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DEPARTMENT OF

# Drainage and Waters

STATE OF MINNESOTA

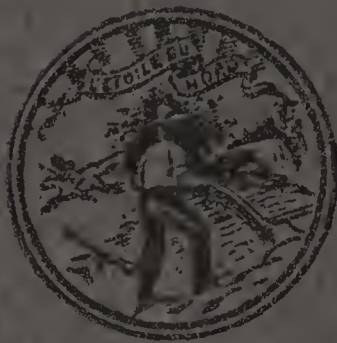
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REPORT ON

## Red Lake Flood Control

E. V. Willard,  
Commissioner.

Adolph F. Meyer,  
Consulting Engineer.



JUNE 15, 1922.



DEPARTMENT OF  
**Drainage and Waters**  
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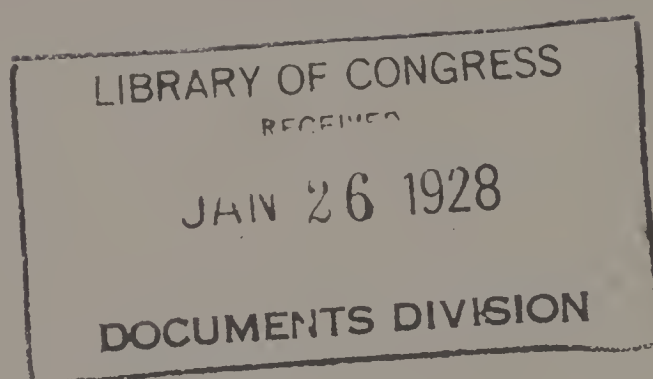


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## PREFATORY REMARKS

The Legislature of 1921 authorized and directed the department to make the necessary engineering investigations to determine and report on the practicability and feasibility of effectuating a plan for the prevention of floods in the basin of the Red Lake River. The report of the department was completed in the summer of 1922, and a limited number of mimeograph copies, was made available to the Board of Directors of the Red Lake Drainage and Conservancy District, the United States War Department, the United States Department of the Interior and a few of the officials and organizations most directly concerned with this improvement. Only a very small number of those who have made requests for this report could be supplied by this method.

The plan outlined by the department in its report follows closely the recommendations made by the United States Engineers in House Document No. 61, Sixty-sixth Congress, First Session, on the same problem. It was adopted by the Board of Directors of the Red Lake Drainage and Conservancy District substantially as submitted, and made the plan of this organization in the subsequent proceedings to establish and construct flood control and drainage outlet improvements along the Red Lake River. While these proceedings were finally dismissed by the court, all indications point to the ultimate adoption of the general project proposed or some modification of this project whenever economic conditions become more favorable and the need for these improvements to provide relief to the fertile lands in this basin becomes imperative.

That the plan reported by the department and adopted by the district, will be the one that will be finally put into effect seems a rational conclusion. Some such plan, though perhaps vague and indefinite, has been discussed and advocated in a general way by leaders in the movement from the time agitation for relief for this section began. It was presented in a more definite and tangible form by the United States Engineers in House Document No. 61. It is worked out in detail in the department's report. There

have been no serious criticisms or exceptions made to any part of the structural plans or any alternate project offered during the court hearings and prior to the dismissal of the proceedings.

In order to supply copies of the report to the numerous individuals and organizations who have made requests therefor, and believing that the matters discussed therein will be of interest to the residents of the territory liable to be affected by the improvements proposed, the report has been published to permit of a more general distribution.

The plan for flood prevention and land reclamation submitted includes within its scope only the lands located within the Red Lake Drainage Basin draining directly into the Red Lake River below the lakes. While use has been made of the Red Lakes to serve as a reservoir or detaining basin in which to store waters in times of heavy precipitation and run-off, direct substantial benefits will accrue only to the lands lying west of the lakes for reasons set forth herein.

The report is not based on purely engineering considerations alone, but efforts have been made by the department from time to time, by such means as could conveniently be employed, to secure expressions of opinions from the various interests who will be affected and may be subject to assessment for the costs of the proposed work. Agricultural interests around the lake are concerned primarily with securing the lowest possible stage in the lakes. This is in conflict with the desires of the fishing and navigation interests, and those who place an aesthetic value on the Red Lakes as a source of pleasure and recreation, all of whom desire that the natural stages and conditions surrounding the lake be maintained as nearly as possible. The basic problem to be solved is the creation of a reservoir in the Red Lakes sufficient to contain the flood waters at times when the river channel below is taxed to its capacity from waters draining into it from tributary areas below the lakes and keep the range of lake levels between the minimum and maximum elevations that will result in the greatest benefit to the greatest number to be affected.

The plan submitted, we believe, offers such a solution. During the time when the plans were being considered, the department was in constant touch with the Board of Directors of the district and their advice and counsel sought and by it freely given; expres-

sions by those who are interested were invited, and a preliminary report on the general plan under consideration was submitted to the Department of the Interior in advance of the preparation of this report in order to secure the views of the Indian interests.

The design of structures have been made with a view of carrying out the general ideas expressed by the United States Engineers in their report upon the plans of improvement of the Red Lakes and the Red Lake River contained in House Document No. 61, Sixty-sixth Congress, to the extent that this has been found practicable and feasible. The change of the location of the controlling dam from that recommended by the War Department in the above report to a point approximately one-half mile further down stream and the addition of other incidental structures made necessary because of this change was adopted to meet the agitation of those who wished to have the dam serve as a foundation for a railroad bridge to serve a railroad projected across the Red Lake River near that point, and to provide a sheltered harbor for lake crafts on the west side of the lake. The location of the dam proposed herein was chosen as a matter of expediency. It possesses no advantages over the site recommended by the United States Engineers when viewed from a purely engineering consideration. The department, however, did not wish to act in the capacity of a court and pass on testimony offered by those who advocated the use of the dam for a railroad crossing, and it is expected that the merits of the location of the dam and the construction of the auxilliary channels and other incidental work will be made an issue before the district and the court having jurisdiction, who, from the evidence which will be submitted during the usual public court hearings which are a part of the proceedings for the establishment of projects of this kind, will decide this matter on what then may appear its merits.

## HISTORICAL

Agitation for the improvement of the Red Lakes and the Red Lake River has been carried on for over thirty years. It has been the subject of numerous surveys and reports\* containing recommendations both for and against undertaking the needed improvements. Disastrous floods recurring at short intervals along the Red Lake River have kept agitation for some form of relief a live issue, but the difficulties involved to adopt a procedure under which a comprehensive plan of improvement could be undertaken have caused continued delays and postponements with corresponding disappointments to the settlers who have made their homes on lands affected by the floods and who must seek the Red Lake River as an outlet for the proper drainage of their lands. All investigations which have had to do with improving the Red Lakes and the Red Lake River have been made by the United States Engineers under the direction of the United States War Department. Prior to the approval by Congress of the rivers and harbors act of July 27, 1916, improvements and expenditures of public funds on rivers and harbor works, in order to come under the jurisdiction of and receive favorable recommendation by the War Department, had to be justified on the grounds that the undertakings would aid and benefit navigation. The importance and value of navigation upon the lakes and river have not suf-

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\*House Document No. 127, Fifty-second Congress, First Session, Dated February 6, 1892.

Annual Report of the Chief of Engineers, 1895.

House Document No. 306, Fifty-fourth Congress, Second Session, Dated February 8, 1897.

House Document No. 67, Fifty-sixth Congress, First Session, Dated December 2, 1899.

House Document No. 671, Fifty-sixth Congress, First Session, Dated May 5, 1900.

House Document No. 539, Fifty-eighth Congress, Second Session, Dated February 10, 1904.

House Document No. 607, Fifty-ninth Congress, Second Session, Dated January 21, 1907.

House Document No. 27, Sixty-first Congress, First Session, Dated May 13, 1909.

House Document No. 483, Sixty-first Congress, Second Session, Dated November 11, 1909.

House Document No. 616, Sixty-second Congress, Second Session, Dated March 9, 1912.

House Document No. 971, Sixty-third Congress, Second Session, Dated April 20, 1914.

House Document No. 1459, Sixty-third Congress, Third Session, Dated November 6, 1914.

House Document No. 61, Sixty-sixth Congress, First Session, Dated May 27, 1919.

ficiently impressed the War Department and Congress to invoke their aid in perfecting the needed lake and channel improvements.

The item contained in the rivers and harbors act, approved July 27, 1916, directing the War Department to make further examination of the Red Lakes and the Red Lake River, in addition to authorizing the devising of plans for the control of the lakes and improvement of the stream in the interest of navigation, empowered the department to consider "any proposition by local interests for participation in the expenses of said project." This authorization resulted in the further investigations and subsequent report made public in House Document No. 61, Sixty-sixth Congress, First Session, dated May 27, 1919. In this report consideration is given to control of floods in the interest of agricultural lands, additional benefits to water powers located on the Red Lake River, improved water supply to municipalities and benefits to navigation, and recommends that a project in which all these interests are made to participate as practicable and feasible. A plan to accomplish these results is outlined, estimates of costs of the required structures are furnished and suggestions are submitted for an equitable distribution of the costs between the several interests to be affected.

In the meantime one of the greatest floods in the history of the state had laid waste large areas of land along the Red Lake River and its tributaries. During the first three days of July, 1919, the United States Weather Bureau reported a rainfall of approximately 9 inches at its Warroad Station. This condition, though less intense, prevailed over the drainage basin of the Red Lakes and the Red Lake River resulting in an unprecedented flood. Before the waters of this flood had receded within the banks of the stream, a movement had been launched by the affected interests to devise ways and means to prevent the recurrence of disasters of this kind.\*

Acting on a petition signed by land owners within the affected territory, the court, Judges Grindeland and Stanton, filed an order establishing the Red Lake Drainage and Conservancy District, dated February 13, 1920. The first Board of Directors of the district selected by the court were made up of the following resi-

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\*See "First Annual Report of the Board of Directors of the Red Lake Drainage and Conservancy District."

dents of the district: C. G. Selvig, Crookston; Andrew Johnson, Gonvick; William Paskewitz, Grygla; Ed. A. Aubol, St. Hilaire and Axel Nelson, Holt. At a subsequent organization of the Board, C. G. Selvig was elected president; C. E. Boughton, Red Lake Falls, attorney; Geo. W. Walker, Thief River Falls, chief engineer; Adolph F. Meyer, Minneapolis, consulting engineer; A. O. Brevik, St. Hilaire, secretary, and S. E. Hunt, Red Lake Falls, treasurer.

The original proceedings were initiated under the provisions of Chapter 442, General Laws, 1917, which authorized the "formation of drainage and flood control districts in river basins adjoining boundary waters." In the meantime the Legislature of 1919, Extra Session, had enacted a somewhat similar statute (Chapter 13, Extra Session 1919) but applicable to drainage and flood control districts affecting river basins located wholly within the state. The petitioners, believing that the latter statute was better suited for the purposes to be accomplished, filed the petitions and proceeded in conformity with this more recent enactment under which provisions the district has since been functioning.

Immediately upon its organization the district proceeded to create a preliminary fund with which to finance its activities, and Mr. Geo. W. Walker, the chief engineer for the Board, began making surveys for the needed improvements. The amount which any district might raise to meet preliminary expenses under the original provisions of the law had been arbitrarily fixed by the Legislature without regard to the size and extent of the projects to be undertaken. It soon developed that the cost of the investigations which would be required in order to prepare the necessary plans and to meet the other expenses of the district, would far exceed the preliminary fund permitted by law. This situation unless remedied, meant that the district would soon reach a limit in its operations and would have to cease its activities for lack of funds.

The situation was called to the attention of the Legislature of 1921, and as a result the limit of the amount that was originally provided to meet preliminary expenses by district organizations was raised and in addition an appropriation of \$25,000.00 was placed to the credit of the State Department of Drainage and Waters with authority for the department to spend this amount

or as much of it as might be found necessary for completing the engineering investigations for the district.

Upon the approval, by the Legislature, of the appropriation for making surveys and preparing plans, the department at once perfected an organization for carrying on the work. Geo. W. Walker, as Chief Engineer of the district, had already made considerable progress on the surveys of the channel of the Red Lake River and at the time the department took over the work, had a party in the field. House Document No. 61, Sixty-sixth Congress, First Session, by the United States War Department, having been made public at about the time when the movement to organize the district had taken on momentum, was used largely as a guide to the district in attacking the problems before it. Federal legislation granting authority to the Bureau of Indian affairs of the United States Department of the Interior to co-operate and enter into agreements with the district for the accomplishment of the purposes in view had been enacted by Congress (H. R. 14311 approved February 21, 1921). State laws had been passed which had made it possible to proceed and bring under the jurisdiction of the district all the various interests concerned.

## MAPS AND PLANS

Maps, profiles and detail plans were prepared as a part of the investigations and included in the original report in the form of an atlas. These data, consisting of the following exhibits are not published as a part hereof.

- Exhibit 1. Map of Red Lake Drainage and Conservancy District.
- Exhibit 2. Maps Showing Location of Proposed Red Lake River Channel Improvement. Sheets 1 to 7 inclusive.
- Exhibit 3. Profile of Red Lake River Channel.
- Exhibit 4. Topographic Map of Lower Tamarac River.
- Exhibit 5. Topographic Map of Lower Black Duck and Cormorant Rivers.
- Exhibit 6. Topographic Map of Lower Battle River.
- Exhibit 7. Topographic Map of Lower Shotley Brook and Dumas Creek.

- Exhibit 8. Topographic Map of Lower Nine Mile, Ten Mile, Hay and Morrison Creeks.
- Exhibit 9. Mass Curve.
- Exhibit 10. Plan of Control Works.
- Exhibit 11. General layout at Outlet of Lake.
- Exhibit 12. Typical Channel Sections.

## ENGINEERING INVESTIGATIONS.

Adolph F. Meyer, Consulting Engineer, Minneapolis, was engaged by the department to act as Consulting Engineer on the investigations. The district organization under Geo. W. Walker, Chief Engineer, had made considerable progress on certain phases of the work, and was kept intact so far as practicable to complete the work under way.

## SURVEYS OF RIVER CHANNEL.

The survey of the channel of the Red Lake River was in progress under Mr. Walker's direction when the department took over the work, and was completed by him and his assistants. The survey consisted in locating the stream by magnetic courses and distances, the taking of levels along the stream and proposed cut-offs and the cross-sectioning of the old river channel. The maps of the channel, bench marks and other valuable data compiled by the War Department as a part of its report contained in House Document No. 61, were used and the plan of improvement outlined and suggestions contained therein were followed as closely as practicable. The preparation of the map of the district, Exhibit 1,\* and of the maps showing the location of the proposed channel improvements, Exhibit 2\*, Sheets 1 to 7 inclusive, were made by Mr. Walker and his assistants under the direction of the department.

## TOPOGRAPHIC SURVEYS.

In order to secure reliable information on the elevations and general physical characteristics of the lands bordering the lake shores, topographic surveys were made and maps prepared of the lower portions of the following streams and of the lake shore in

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\*Exhibits not included in this publication.

the immediate vicinities of their outlets into the lake: Tamarac River, Black Duck River, Cormorant River, Shotley Brook, Dumas Creek, Nine Mile Creek, Ten Mile Creek, Hay Creek and Morrison Creek. The primary purpose of these surveys was to determine what effect the raising or lowering of the lakes might have on the low lying lands bordering the streams which outlet into the lake. With this in view chief consideration was given the areas lying between contour 1175, the average elevation of the lake surface, and contour 1180, five feet above. Mr. L. J. Lubins, Assistant Engineer of the Department, was in charge of the field work covering these surveys.

### MISCELLANEOUS FIELD OBSERVATIONS

Gages were established at Washkish and Red Lake Agency on the Upper and Lower Red Lakes respectively, where observations of lake levels have been and are being taken weekly by observers engaged by the department. Gaging stations on the Red Lake River at Crookston and Thief River Falls, and one on the Thief River near Thief River Falls, have been maintained by the department in co-operation with the Water Resources Branch of the United States Geological Survey for several years past, with regularly employed observers who are taking daily observations of flow. In addition to the regular gagings and meterings above referred to, special measurements of outflow from the lakes have been taken at various times during the investigations. Observations as to past lake stages as evidenced by high water marks along the shores; material surveys on which to base construction costs and miscellaneous investigations which have been found advisable and necessary for an intelligent consideration of the problem, have been made from time to time by men delegated by the department.

### ANALYSES OF DATA AND DESIGN OF STRUCTURES

The analyses of available data, the adoption of a plan for the accomplishment of the purposes which it is believed will result in the greatest benefit to the greatest number to be affected, and the design of structures have been under the direct supervision of Mr. Meyer. In view of the almost complete lack of data on past lake stages, and on inflow and outflow on which to base designs,

credit for the results is due to his untiring efforts and his close application to the problem.

The federal law granting authority to the district to co-operate with the Bureau of Indian Affairs to undertake improvements affecting the Red Lake Indian Reservation stipulates (1) that the plans to be followed shall in general be in conformity with the outline and suggestions contained in the report of the War Department published in House Document No. 61 "with such modifications and changes as may be found advisable"; (2) that all plans shall be submitted to and be approved by the Secretary of War and the Secretary of the Interior; and (3) the specific provision that "before the acceptance of the plans the Red Lake Drainage and Conservancy District and the Secretary of the Interior shall ascertain and agree upon the maximum and minimum levels between which the water in the Red Lake shall be permitted to be fluctuated," etc.

The department has kept these provisions of law and the limitations imposed by them constantly in mind during the investigations. The plans, suggestions and discussions contained in House Document No. 61, have been followed as closely as practicable. It will be apparent however, from a study of Mr. Meyer's report that some of his conclusions differ somewhat from those presented by the United States Engineers. A careful study of their report indicates that the Government Engineers recognized the need for further investigation of a number of the factors involved before final conclusions were drawn. In view of the incomplete and inadequate physical data available, it is not to be wondered at that further investigations have resulted in somewhat modified conclusions. As pointed out by Mr. Meyer, a greater lack of physical data bearing on such an important problem as that of the control of the Red Lakes is hardly conceivable.

In order to secure the approval of the lake levels to be established by the proposed control of outflow from the lakes in advance of the completion of designs of structures, a preliminary report was prepared and submitted to the Department of the Interior. The report was presented and discussed in person by Mr. Meyer before the Bureau of Indian Affairs in November, 1921, and with certain modifications as to proposed lake levels, was approved in February, 1922. Subsequent investigations and designs of struc-

tures have been made with a view of complying with the fundamentals laid down in this report.

Mr. Meyer's report to the department, in full, contains a detailed discussion and presentation of the proposed plan of regulation of outflow from the lake; the maximum and minimum lake stages that may be expected to prevail under the proposed control and its effect upon present and past stages.

Believing that the subject of benefits to water powers is one, the proper determination of which must be based on scientific and technical treatment, at the specific request from the department, Mr. Meyer has included in his report a presentation of this phase of the project.

### STATE LAWS LIMIT ASSESSABLE AREAS

The final determination of what lands will be benefited by the proposed project and how much each piece and parcel of land should be assessed on account of the cost thereof, is the work of the viewers to be appointed by the district should the board decide to continue the proceedings to a final conclusion. A general brief discussion of this subject, however, with a view of pointing to some of the conditions which are peculiar to this drainage basin, and of the fundamentals which should govern the viewers in dealing with the subject of appraisals, is believed to be a logical part of a report of this nature.

On page 28, House Document No. 61, 'Sixty-sixth Congress, First Session, the United States Engineers make this statement in discussing the manner in which the costs of the project should be allotted to the several interests to be affected:

"Lands which will be benefited by the proposed improvements and which are now or will be benefited by drainage systems tributary to Red Lake and to Red Lake River above Kratka, as shown in Executive Document No. 27, Sixty-first Congress, First Session, and in Executive Document No. 971, Sixty-third Congress, Second Session, have an area approximately as follows:

Within the Indian Reservation.....	236,800 acres
Outside the Indian Reservation.....	248,500 acres
<hr/>	
Total .....	485,300 acres

“The ditching projects already completed had a cost varying between \$1.00 and \$2.00 per acre. Therefore it would seem reasonable to assess these lands \$1.00 per acre for benefit to be derived from the proposed improvement of the Red Lake River, which will give them improved drainage and flood prevention. This assessment rate per acre would produce from:

Indian lands.....	\$236,800.00
Private and other lands.....	248,500.00”

It is quite evident that the War Department when it suggested that this vast area be assessed at the rate of an average of \$1.00 per acre towards the improvement of Red Lake and Red Lake River did not reckon with the limitations imposed upon the viewers in ditch proceedings by the public drainage laws of the state of Minnesota in the matter of making assessments for benefits. It is agreed that the estimates of the number of acres within the district which are in need of drainage or which have benefited by drainage ditches already constructed as given in their report is probably as nearly correct as any that can be made with the limited information available on which to base such an estimate, but the fact remains that under the provisions of the laws under which the district operates no such areas can be included and made assessable for benefits under the proposed project.

All assessments of costs for drainage improvements must be justified on the grounds that benefits to lands are “direct benefits.” In view of the fact that all of the structures are to be perfected west of the lakes and since under the proposed control the lakes will not be lowered by more than about 1½ feet from the stages which have prevailed in a state of nature, none of the lands tributary to the streams outletting into the lakes can be assessed as being directly benefited. While the lands bordering immediately on the lake shore will be benefited by the lowering of the lake as above indicated, the extent of such benefits will be so difficult of determination because of their intangible nature that it is doubtful if an attempt to assess such shore line lands will produce any net results to the district. For these reasons, I think it may be assumed from the outset that in so far as the lands bordering on the lake as well as those which are located along the streams outletting into the lake are concerned, no assessments can be made for the proposed improvements under

the provisions of the now existing laws. It would appear therefore, that the portion of the costs of the project assessable to agricultural lands must be allotted to the lands located in the water-shed of the Red Lake River, west of the lakes.

### LOCATION OF LANDS SUBJECT TO BENEFITS

The lands which comprise the area subject to benefits by the proposed improvements, either by way of reclaiming them from floods or by affording them the necessary drainage outlet are made up of all or portions of the following townships:

Within the Indian Reservation; townships 151, 152, 153 and 154, north, range 36 west; townships 151, 152, 153 and 154, north, range 37 west; and townships 152, 153 and 154, north, range 38 west.

Outside of Indian Reservation; townships 152 and 153 north, range 39 west; townships 152, 153 and 154 north, range 40 west; and townships 152, 153 and 154 north, range 41 west.

### PHYSICAL CHARACTERISTICS OF WATERSHED WEST OF THE RED LAKES

The area comprising the watershed of the Red Lake Basin between the outlet of the lake and Highlanding (section 28, township 153 north, range 40 west) is a flat plain almost entirely devoid of relief. The course of the stream over this distance is not defined by the usual valley between bordering hills and bluffs such as that which ordinarily defines the courses of streams in the southern sections of the state, but flows between low banks with a fall in a state of nature of an average of about six tenths of a foot per mile. The land rises gradually and uniformly from the thread of the stream north and south to the outside boundaries of the drainage basin. The divide between the watershed of the Red Lake River and the Clearwater River to the south is indefinite and during times of high floods in the Red Lake River the water passes over the divide into the Clearwater River. The territory north of the stream rises gradually and uniformly for a distance at the widest portion of the drainage basin of about 18 miles at a rate of from two feet to two and one-half feet per mile.

There are no tributaries or natural drainage outlets traversing this area into which surface waters may accumulate to be carried to the main channel of the river. The water surface within the channel of the stream at normal and low stages is only from two to four feet below the bordering meadows. As a result the entire area is more or less swampy in character and all of it in need of artificial drainage before the lands can be successfully used for ordinary farming purposes.

## DISCUSSION OF BENEFITS

In instances where the relief of the effected territory is pronounced and where lands in need of drainage are located so that an adequate outlet may be found in natural creeks or ravines other than the main outlet channel it has been established by the courts that under our present drainage laws such lands cannot be assessed for the cost of improving some other or ultimate outlet because of discharging added waters into such outlet. In the case of the Red Lake River, however, all lands included within the limits of the area described must seek the channel of the Red Lake River as the outlet for public drainage ditches as there are no other points at which such ditches can be made to terminate. It is apparent to all who have viewed conditions along this stream that the river in its present state cannot be made to function as an outlet for lateral drainage. The obligation to share in the costs of the proposed improvements must therefore not only be made to rest with those whose lands lie adjacent to the channel and are subject to overflow, but likewise with those who own lands in other parts of the watershed but who are dependent on an enlarged channel to serve as an outlet for the drainage of their lands through laterals which must be made to terminate in the main channel of the river. Unless the viewers find benefits along the lines suggested, equitably determined, and the courts will uphold their findings as being "direct benefits" in the legal meaning of the term, by no other method of distributing the costs can the people of this territory ever hope for relief under the present existing drainage laws, if all or any considerable portion of the costs of the necessary improvements are to be assessed against agricultural lands.

## DISTRIBUTION OF COSTS

It is estimated that the areas which will be directly benefited by the proposed improvements either by way of reclamation from floods or by reason of being furnished adequate outlet for drainage are approximately as follows:

Within the Indian Reservation.....	160,160 acres
Outside of the Indian Reservation.....	85,600 acres
<hr/>	
Total .....	245,760 acres

The estimated cost of the project as shown in "Summary of Cost Estimates" hereof is approximately \$570,350.00. In Meyer's discussion of "Benefits" he gives it as his opinion that "on the basis of the equitable distribution of costs among the interests in whose behalf the expenditure is incurred, and with due regard to the total cost of a project designed solely to benefit any one given interest and without consideration of benefits conferred by the proposed improvement, the water power interests should pay about \$150,000.00 plus part of the annual operation and maintenance expenses." The determination of benefits to cities and municipalities because of an increased and improved water supply has not been given consideration beyond the study of the effects on these interests by the improvements, made by the United States Engineers and published in House Document No. 61. Fixing arbitrarily this amount at \$25,000.00 and the share of the federal government at \$15,000.00, the apportionment of the costs of the project would be as follows:

Lands within the Indian Reservation.....	\$247,650.00
Lands outside the Indian Reservation.....	132,700.00
Water powers.....	150,000.00
Municipal water supply.....	25,000.00
Federal government.....	15,000.00

Based on the above estimated acreage subject to direct benefits and on the above method of apportioning the costs, the average cost to benefited lands will be approximately \$1.55 per acre.

This distribution of costs is submitted merely for the purpose of expressing the costs of this project to the several interests in terms of dollars and cents based upon the assumptions made, and on the further assumption that the water powers may be assessed

their share of the costs in the same manner as benefited agricultural lands are ordinarily assessed in the usual drainage proceedings. The statutes provide that the benefits to lands shall be determined by a board of viewers as a fixed amount and when confirmed by the court at the time the project is ordered established shall constitute a lien against said lands in an amount equal to the proportionate share of costs properly chargeable on account of the proposed improvements, said lien to be secured by the property assessed and made payable in installments covering a period of usually twenty years.

Should the district find that it will not be possible or advisable to assess benefits against the water powers in the same manner as agricultural lands, the law under which the district is organized authorizes the levying and collection, by the district, of an annual rental for "such greater, better or more convenient use of or benefit from the water supply of the district." The rental or rate of compensation to be paid by the powers under this provision will be fixed annually by the district, subject to review by the courts, and will be a source of revenue extending through an indefinite period and which may be applied to the expenses of the district. Under the annual rental plan of collecting the benefits from the water power interests, it appears evident that the total initial cost of the project must be assessed against the other interests, in which case the average assessments against agricultural lands will approximate \$2.25 per acre. If, however, the annual rental plan can be adopted and applied by the district in securing the payment of benefits from water powers the amount that the agricultural lands and the other interests will actually have to pay, should be less than under any other plan that suggests itself in the statutes under which the district operates. This becomes evident from the discussion of this subject under the caption "Benefits" of Mr. Meyer's report.

The difficulty of making an equitable assessment of benefits against the water powers at a time when some of the most valuable power sites are still undeveloped will become evident to the district and to the courts under whose direction the proceedings are to be put through. It is believed, therefore, that the adoption of the annual rental plan will result in a more equitable distribution of the costs between the various water power owners and

will bring a larger aggregate income to the district. In the consideration of the adoption of this plan it is suggested that the statutes be clarified so as to grant unquestioned authority to the board of directors to apply the income from such rentals for the payment of the bonds of the district as well as current expenses.

The desirability of enacting legislation which will grant authority to the district to extend the time in which a portion of their improvement bonds shall become payable beyond the twenty years now stipulated by law merits consideration. (Since a number of years will elapse before all of the water power sites on the Red Lake River are developed and since the annual benefits to water powers will be dependent upon the rainfall and will therefore vary from year to year, it is readily conceivable that the largest annual benefits will not become due until towards the end of the twenty year period for which the improvement bonds are issued. This suggests the desirability of the district being empowered to issue some longer time bonds carrying a portion of the costs of the improvement, these bonds to be retired by annual payments made by the water powers for annual benefits derived from the head-water improvement.

## SUMMARY OF COST ESTIMATES

### SUBDIVISION "A"

#### Jetties

15,312.5 cubic yards loose rock in place at	
\$4.00 .....	\$61,250.00

### SUBDIVISION "B"

#### Control Works

4,960 cubic yards of excavation.....	\$5,000.00
2,560 lineal feet round piling in place...	1,360.00
11,200 feet B. M. sheet piling in place....	784.00
4,300 feet B. M. Back Lash wall in place	323.00
1,512 cubic yards concrete in place.....	18,180.00
15,300 pounds reinforcing steel in place..	690.00
12,400 feet B. M. lumber for stop logs, fishway, etc.....	970.00

Six sluice gates, six sets of racks, stop log hoist including track and miscellaneous steel .....	4,800.00	
110 cubic yards rip-rap in place.....	770.00	
Back fill.....	750.00	
Coffer dam and pumping.....	2,500.00	
Contractor's profits.....	3,633.00	
Construction camp, other temporary structures and equipment shrinkage.....	3,000.00	\$42,760.00

### SUBDIVISION "C"

#### Miscellaneous Items in Vicinity of Control Works

Right-of-way for control works and approach channel.....	\$800.00	
One mile detour road.....	1,500.00	
6,500 lineal feet of ditch outside of spoil banks to intercept seepage—8,163.7 cubic yards at 25c.....	2,040.92	
72 lineal feet 42-inch corrugated metal culverts in place.....	425.00	
18 miles of telephone lines.....	2,500.00	
Caretaker's dwelling, shop, etc.....	7,000.00	\$14,265.92

### SUBDIVISION "D"

#### Channel Improvement

Main channel, Station 0 to Station 52, 95,541 cubic yards at 15c.....	\$14,331.15	
Auxiliary channel "A," 24,428 cubic yards at 15c.....	3,664.20	
Auxiliary channel "B," 19,933 cubic yards at 15c.....	2,989.95	
Auxiliary channel "C," 23,315 cubic yards at 15c.....	3,497.25	
Auxiliary channel "D," 11,031 cubic yards at 15c.....	1,654.65	
Material to complete sand fill back of jetties, to be borrowed outside of jetties, 15,805 cubic yards at 15c.....	2,370.75	
Main channel, Station 52 to Station 830, 1,634,351 cubic yards at 9.5c.....	155,263.35	

Right-of-way, Station 52 to Station 830, 256 acres at \$20.00.....	5,120.00	\$188,891.30
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## SUBDIVISION "E"

### Channel Improvement

Main channel, Station 830 to Station 2283, 2,160,963.6 cubic yards at 9.5c.....	\$205,291.54	
Right-of-way, Station 830 to Station 2283, 458 acres at \$25.00.....	11,450.00	
Passing dredging plant through highway bridge at Station 1628 (Highlanding)..	500.00	
Passing dredging plant through highway bridge at Station 2130.....	500.00	\$217,741.54

## GENERAL EXPENSES

Estimated cost of future engineering super- vision, attorney fees, auditor's and clerk fees, district organization expenses, and all general administrative costs up to the completion of the project.....	\$50,000.00
Total estimated cost of project.....	\$574,908.76

## ACKNOWLEDGMENTS

The department desires to express its appreciation and indebtedness to the following who have furnished data and in various other ways have assisted in the investigations and in the preparation of this report: Mr. Adolph F. Meyer, who, as Consulting Engineer, has given liberally of his time to the work, and to whose able analytical application to the problems to be solved is due the credit for the proposed system of regulation; to the United States Engineers, particularly to the St. Paul office, who have co-operated whole heartedly at all times; to the Board of directors of the Red Lake Drainage and Conservancy District and the members of its organization; to the United States Geological Survey and its organization; and to all other citizens and organizations who have rendered valuable aid during the progress of the work.

## REPORT OF A. F. MEYER, CONSULTING ENGINEER

Minneapolis, Minn., May 25, 1922.

Hon. E. V. Willard,  
Commissioner of Drainage and Waters,  
Saint Paul, Minnesota.

Dear Sir: I am submitting herewith my report on certain phases of the Red Lake Improvement which you have referred to me for investigation. The survey of the present channel of Red Lake River and the detailed computations relating to the improvement of the River, after the general design had been agreed upon, were conducted under your direct supervision; therefore a detailed discussion of this part of the project is not included here.

### SUMMARY OF PROJECT FEATURES

The Red Lake Project may best be considered in three parts: first, the proposed lake levels and the control of outflow; second, the required controlling works; and third, the necessary channel improvement.

#### The Proposed Lake Levels and Control of Outflow

It is proposed to establish 1,174, Sea Level Datum, as the ordinary high-water level. Whenever the Lake rises above this level, the inflow into the Lake shall be wasted through the controlling works at the outlet substantially as fast as the stage of Red Lake River will permit. Whenever the level of the Lake is less than 1,174, the water shall be conserved for beneficial use, both in the lake and on the river below; provided that whenever there are indications of a large spring inflow, water shall be wasted during the winter months, in order to provide storage capacity for the expected spring flood water.

Whenever the lake stage, the rate of inflow, and the season of the year indicate that the storage above 1,172 will be exhausted, the rate at which water is being released for beneficial use in power development shall be reduced to such an extent as in the judgment of those in charge shall prevent the Lake from being drawn down to 1,172 before the following spring; provided that whenever the level of the Lake reaches 1,172, the outflow shall be limited to

a rate of 150 cubic feet per second, or such lower rate as may be required for municipal water supply and sewage disposal purposes, provided, however, that such lower rate of controlled outflow shall never be less than the rate which would prevail under the existing climatic conditions if no artificial regulation had been in force.

Under the recommended system of control, the maximum lake level will be lowered about  $1\frac{1}{2}$  feet, the minimum will be lowered  $1\frac{3}{4}$  feet, and the mean lake level will be lowered nearly 2 feet. If this system of control had been in effect during the past twenty years the lake level would have been between 1,172 and 1,174 half of the time. It would have been somewhat above 1,174 for about a quarter of the time, but the lake level would not have reached 1,175 during either of the greatest floods for which we have any records, namely, those of 1916 and 1919. Climatological data indicate that there may have been a still greater flood during the summer of 1905. The Lake could have been prevented from exceeding 1,175 during this year also if the control works had been opened wide notwithstanding the overburdened condition of the lower river. In my judgment, however, it would have been preferable to let the Lake rise 3 or 4 inches above 1,175 during such extraordinary rainfall if by doing so the lands below could have been protected, since the lake level would still have been nearly a foot lower in 1905 under control than it was in a state of nature.

During the exceptionally dry period between 1910 and 1913, it would have been necessary to draw down the Lake to its minimum stage of about 1,171.3.

Charts 1 to 21 show graphically on the upper half, the observed or estimated stream flow at Crookston, the computed natural outflow from Red Lake and also the rate at which the water would have been released from the Lake if the outflow had been regulated as herein proposed. The lower half of the chart shows the computed natural level and the level which would have prevailed if the proposed regulation had been in force during this period of years from 1901 to 1921.

The levels herein referred to are mean lake levels. High winds at times raise the Lake at one end and lower it at the other.

## The Controlling Works

It is proposed to build a controlling dam in the Red Lake River about 3,400 feet below the outlet of the Lake, for the purpose of regulating the outflow in the interest of drainage, flood control, power development, navigation, and municipal water supply and sewage disposal. A general plan of the control works and typical cross-sections of the structures are shown on Exhibit 10.\*

The proposed structure consists of five wasteways, each 10 feet 6 inches wide. Three of these are controlled by hand-operated sluice gates. These gates are protected by coarse iron racks. Stop logs are provided for emergency use in closing of both ends of these sluices.

An overhead travelling hoist, with a capacity of one ton, is provided for handling stop logs, racks and debris accumulating in front of the racks.

The trash racks for each sluice are built in four sections, each consisting of seven 5/16-inch x 4-inch vertical bars spaced 4 inches apart.

On account of the necessity for frequent changes in discharge to meet the requirements of the proposed regulation it is important to be able to operate the controlling works conveniently, particularly during the severe winters prevailing in this region. For this reason the sluice gates are placed so as to be below ice level even at extreme low water with four feet of ice cover, and the gate stems pass through oil-filled pipes to prevent their freezing in.

The weir below the sluice gates serves the dual purpose of submerging the gates and slowing down the water as it emerges at high velocity. Water discharged through a single sluice gate cannot flow at high velocity horizontally along the apron. It will raise the pool back of the weir and will cause comparatively uniform flow over the entire 31½ feet length of the weir crest. The relatively thin, overfalling sheet of water flowing into the pool below the weir will effectually destroy the energy of the water released at high velocity through the sluice gate and prevent scour below the apron. Openings placed in the piers both above and below the weir will make the entire 31½ foot length of weir

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\*Exhibits not included in this publication.

and pool active at all times, even though all the discharge comes through one 4-foot opening. In this way, high, destructive, horizontal velocities over the apron are effectually prevented.

One 10 foot 6 inch open sluice is provided for passing ice, logs and debris, if desired, and another sluice of the same width for occasionally locking through small boats. Both of these sluices are also used for discharging flood water. Small hand-operated gates are provided for filling and emptying the sluice which may be used as a lock chamber. Stop logs are provided in place of lock gates at the ends of the sluice. A fishway is also provided.

Provision is also made for a single-track railroad crossing and a 20-foot highway bridge is provided.

The approach channel divides into several branches about 2,400 feet above the control works, one for boats and for carrying the discharge to the dam, one for saw logs and a third for ties, plup wood, etc.

In order to prevent the filling in of the dredged approach channel, jetties are to be built about 1,700 feet out in the Lake. These jetties are to be carried about 2 feet above ordinary high-water level in the Lake. The ends of the jetties are to be built 5 feet above highwater. A plan of the jetties and channels at the outlet of the Lake is shown on Exhibit 11.\*

### **The Channel Improvement**

For the purpose of providing an outlet for the ditches draining the lands within the Red Lake River basin, it is proposed to widen, deepen and straighten the Red Lake River by providing a dredged channel, 60 feet wide at the bottom with a grade of 0.71 feet per mile, between the outlet of Red Lake and a point near Kratka, a distance of approximately 45 miles along the present channel. The improved channel will carry 1,000 cubic feet per second at a stage of 1,171.6 just below the controlling dam. This stage will average three feet below the general level of the banks in the upper and lower reaches and more in the middle.

Whenever the entire channel capacity is required for carrying off water discharged by the drainage ditches, or the stored water

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\*Exhibits not included in this publication.

must be conserved for beneficial use, the controlling works at the outlet of the Lake shall be closed. Whenever water must be wasted from the Lake, the rate of release shall be governed by the channel capacity available over and above that required for drainage purposes in the basin below.

After heavy rains, when the improved channel is required to carry off the discharge from the drainage ditches, the effective capacity of the channel is increased in the lower reaches. This is due to the fact that whereas the cross-section of the channel remains virtually constant, the size of channel required becomes smaller and smaller as the Lake is approached, because the tributary drainage area becomes smaller. For this reason, when the upper reach of the improved channel rises to its normal stage, the slope of the water surface in this reach will be considerably less than that corresponding to 1,000 c. s. f. discharge at the dam. This will permit the water in the middle reach, where the banks are considerably higher, to rise until the slope in the lower and middle reaches is greater than the average slope when 1,000 c. s. f. is being discharged from the Lake, and therefore the effective capacity of this portion of the channel under the conditions stated is materially augmented. In effect, therefore, the channel is larger in the lower reach than in the upper.

The total area tributary to the improved channel is about 370 square miles. It is relatively flat and "slow." Therefore the rate of run-off will be comparatively small during all ordinary rains. The lower reach of the improved channel will carry 1,800 c. s. f. at less than bank-full stage when little or no water is being discharged from the Lake. This is equivalent to an average of 5 c. s. f. per square mile from the tributary drainage area. This rate of flow was not reached in the Thief River during the flood of 1916. The ordinary flood flow of this stream is less than 2 c. s. f. per square mile. The channel capacity provided in the Red Lake River is believed to be as great as can be justified. The small savings which would accrue from the prevention of occasional crop losses from rare floods would not pay for the cost of the additional improvement required. Moreover, during protracted periods of excessive summer rainfall, heavy soils become practically saturated and local ditch systems usually are unable to prevent crop losses. Very thorough tiling, alone, can meet such a contingency.

That it is impracticable to provide drainage ditches of a capacity equal to taking care of extreme flood runoff is well illustrated by the July, 1909 flood on the Wild Rice River. At Twin Valley, Minnesota, where the tributary drainage area is 805 square miles, the flood flow exceeded 10 c. s. f. per square mile if the records are correct. This flood was caused by "cloud-burst" rainfall which averaged over 8 inches in twenty-four hours over the entire drainage area. Such a flood will probably not recur on this watershed more often than once in a century or more. One crop loss in such a long period of time has a negligible effect on the value of purely agricultural land, yet to prevent such loss the expenditure for channel improvement and open ditch construction would be more than doubled.

## DISCUSSION OF THE PROJECT

### Basic Data

#### Stream Flow Data Inadequate

The development of this project has been seriously handicapped through want of basic physical data. In fact a greater dearth of data on which to base an important project is hardly conceivable. The added cost entailed by the engineering studies necessary to secure even a reasonably secure hydrological foundation for the project would have paid for collecting the most essential data during the past years if the work had been taken in hand in time. The possible savings in the cost of the necessary structures entailed through the necessity for providing larger factors of safety—or better, factors of uncertainty—would many times over have paid for the cost of securing the necessary observational data during past years. If taxpayers fully appreciated the value, to them, of topographical surveys and hydrological observations generous appropriations for this work would be forthcoming.

No records of outflow from Red Lake are available except a few meter measurements made during the past year. However, the data of Table I are useful in estimating the probable outflow from Red Lake and the probable inflow into the Lake during past years. The daily records of the discharge of Red Lake River above the mouth of Thief River, taken between May, 1899, and August, 1901, are valuable because a rather accurate estimate of outflow from Red Lake can be based on them by deducting the estimated runoff from the local drainage area of 450 square miles.

## Estimation of Red Lake Outflow

No records being available, estimates of the outflow from Red Lake (drainage area, 1950 square miles) between July, 1909, and September, 1917, were made in the following manner: From the flow of Red Lake River at Thief River Falls, (drainage area, 3,430 square miles), for the months for which data were available, there was first deducted the flow of its principal tributary, the Thief River (drainage area 1,010 square miles). Then it was assumed that the local drainage area of 470 square miles between the outlet of Red Lake and Thief River Falls contributed runoff at a rate per square mile equal to the average runoff per square mile of the Thief River and the Clearwater basins adjoining it. This local runoff was subtracted from the flow of the Red Lake River after deducting the flow of the Thief River, and the remainder, with minor modifications, was assumed to represent outflow from Red Lake. By this method of computation the natural equalizing effect of Red Lake on Red Lake River is given proper weight. These computations are given in Table II. The total outflow derived in this manner does not differ widely from that given in House Document No. 61, Sixty-sixth Congress, First Session, 1919, but as will be seen by Table III, its distribution through the year does differ materially.

The estimates of outflow during the winter months and during years for which the stream flow data utilized as above stated were not available, are based mainly on climatological data. The details of the method used will be discussed later.

## Estimation of Red Lake Inflow

The total net or utilizable inflow into the Lake between any two dates on which the lake level was the same must be equal to the outflow from the Lake. This net inflow may be considered as consisting of the runoff into the Lake from the land area plus the yield of the water area. The runoff from the land area represents the precipitation minus the evaporation and transpiration loss from that area. The yield of the water area is the precipitation on the Lake minus the evaporation from the lake surface. This evaporation was computed from the observed monthly mean air temperature at Red Lake by means of Figure 150 (Page 217, *The Elements of Hydrology*, by Meyer). The rainfall on the

lake surface was computed from the Weather Bureau records of rainfall at Red Lake and other stations nearby.

The total outflow from the Lake for the period between July, 1909, and September, 1917, was computed from the monthly estimates previously made. From this total there was deducted the yield of the water area, which was very small. The remainder constitutes the total runoff from the land area for the given period of time. This portion of the total net inflow into Red Lake was assumed to have been distributed through the entire period in the same manner as the runoff from the land area between Red Lake and Crookston.

For the period 1899 to 1909, both inflow and outflow were estimated mainly from climatological data. From the monthly mean precipitation and temperature the evaporation and transpiration losses for the land area of 1,516 square miles tributary to Red Lake were first computed. From these the monthly runoff into the Lake was computed by my method described in Chapter IX, "The Elements of Hydrology." To the runoff from the land area was added the yield of the water area and thus the net monthly inflow into the Lake was derived.

On the basis of the past year's meter measurements of outflow from Red Lake and lake stage, the discharge records of Red Lake River above the mouth of Thief River, and the computed inflow during 1899 to 1901, an approximate relationship between lake stage and discharge was derived. It was appreciated that in winter ice conditions, and in summer weed growth in the channel below the outlet, affect this relationship.

From the computed inflow and the relation between lake stage and outflow, the natural outflow from Red Lake and the approximate natural lake levels between 1899 and 1909 were computed. A summary of these computations is given in Table IV.

The inflow and outflow for the period September, 1917, to July, 1921, for which only incomplete records were available, are based on a combination of the several methods used for the other periods.

It appears from Table IV that the net monthly inflow into Red Lake is frequently negative; in other words, the runoff from the land area plus the rainfall on the lake surface is insufficient to supply the evaporation.

In considering the probable accuracy of my predictions relative to future lake stages and discharges, it must be remembered that my conclusions are necessarily based on very inadequate data. Some hydrological basis for the project was necessary. The analysis adopted is believed to be the best one applicable and leading to sound conclusions. No alternative presents itself except that of postponement of the entire project for at least ten years while the necessary records of inflow, outflow and lake stage are being secured.

### Lake Level Records

Other basic data, conspicuous by their absence, are continuous readings of the level of Red Lake. Table V gives the only available instrumental determinations of lake levels. These were made by several governmental departments during the past years. The readings of the lake levels taken at the Red Lake Agency by A. C. Goddard, and published without comment in the first annual report of the Conservancy District, contain so many outstanding discrepancies as to make them of little value. This is true even after the figures given as hundredths of a foot are changed to tenths, as all of them evidently should be.

Recently we secured from Mr. W. M. Everts, Ditch Engineer, Beltrami County, Bemidji, Minnesota, levels observed on the east end of upper Red Lake at Washkish in connection with some drainage improvements. These are given in Table VI. The original records have been reduced by 1.15 feet in order to approximately reduce them to the Sea Level Datum used in this report.

On Page 17 of House Document No. 61 the statement is made that Red Lake reached 1,178.1 in 1916. Apparently this is based upon the statement of Mr. O. L. Dent, (Page 12 of House Document No. 61). The reading of 1,178.1 has also been furnished by W. M. Everts of Bemidji as representing high water in the **Upper Lake** during 1916. This level, however, needs to be reduced by about 1.2 feet to change it to the Sea Level Datum here used, and applying a further reduction of about 0.3 feet, the estimated difference between the levels of the Upper and Lower Lakes at high water, brings the reading down to about 1,176.6 as the probable high water level of the **Lower Lake**. Water marks on the shores of the Lake confirm this estimate of natural high water.

Statements of men who have been familiar with Red Lake for many years indicate that during the low-water period of 1910 to 1912 so much difficulty was experienced by logging interests in getting logs out of the Lake that the outlet was deepened by dredging. If such is the case, then Red Lake has been lower during the past ten years than previously. An instrumental determination of lake level made October 25, 1907, shows an elevation of 1,174.7. Recent September and October levels, except during 1915 and 1916, appear to be somewhat lower. However, the year 1907 was preceded by several years of high water, so that the fall lake level of that year is more nearly comparable with the fall levels of years like 1915 and 1916. On this basis present lake levels are probably not over half a foot lower than the prevailing levels of twenty years ago. This conclusion is borne out by comments made in early reports on Red Lake regarding the shallow water found near the south shore of the Lower Lake during early years. For example, on Page 15 of House Document No. 127, Fifty-second Congress, First Session, 1892, the statement is made: ". . . along the south shore of the southern lake an enormous flat extends many miles out into the Lake with scarcely enough water to float a canoe in many parts."

From these limited data it appears that the minimum level reached by the Lower Red Lake during the past ten or fifteen years was about 1,173, Sea Level Datum. The high water level reached by Lower Red Lake during the extraordinary flood of 1916 was about 1,176.5. The Upper Lake is usually at a stage one or two tenths of a foot higher than the Lower Lake, because most of the inflow comes in through the Upper Lake.

## REGULATED LAKE LEVELS

### Requirements of Interests Concerned

In deciding upon the most desirable levels for Red Lake, due consideration was given to all interests concerned. As in all projects of this character, the requirements of the several interests conflict considerably. Some of the low lands bordering the streams entering Red Lake from the east would require a lowering of the Lake of at least 3 or 4 feet for their reclamation. Interests navigating the Lake and using the shores of the Lake for summer resort purposes require a moderately high lake level,

maintained as uniformly as possible throughout the season. Fishing interests require the maintenance of natural conditions as nearly as possible, with the natural fluctuation in level further reduced. The drainage of agricultural lands lying west of the Lake, below the outlet, requires the holding back of flood waters within the Lake so that the channel of Red Lake River may be utilized as an outlet for drainage ditches. Municipalities using the waters of Red Lake River for water supply and sewage disposal purposes need to have the extreme low water flow increased, necessitating a fluctuation in lake levels. Water power interests require a large winter flow, necessitating the greatest practicable fluctuation in lake level, but are not concerned with the particular levels selected as the maximum and minimum so long as the same range is maintained.

Drainage of the land surrounding Red Lake itself is not impeded at present lake stages, except for about 10,000 acres that border the Tamarack, Blackduck and other small streams flowing into the Lake. Much of this 10,000 acres is covered with from one to three feet of peat and could not be reclaimed unless the Lakes were lowered three or four feet. Other areas, however, can be reclaimed by local drainage at the proposed lake levels.

In general, the land around Red Lake is wet and swampy because both evaporation and natural surface drainage are retarded by vegetation and not because the level of Red Lake is too high. There is ample fall available for drainage ditches except on the restricted areas above referred to. Damage to fishing, navigation and summer resort interests—judged from the viewpoint of both present and prospective importance—together with the increased cost of the outlet channel, overbalance all possible advantages to agricultural interests which might result from a lowering of Red Lake three or four feet below its natural level, as has been proposed by some. For every additional acre that could be drained if the Lake were lowered three or four feet, there are a hundred acres in the drainage basin of Red Lake and Red Lake River which can be economically drained at present lake stages.

The lands bordering Red Lake River are not concerned with the lake levels at all. Their need is for outlets for the drainage ditches discharging into Red Lake River and the improvement of the stream for this purpose. These lands are, however, concerned

with the proposed control of the outflow from the Lake, as flood water must be held in Red Lake while the improved channel is carrying away the runoff contributed by the drainage ditches.

The fishing interests have been insistent upon the maintenance, as closely as practicable, of the natural regimen of lake levels. They have pointed out that Red Lake is one of the best existing sources of whitefish in the state, and that the spawning beds of these fish would be seriously disturbed if the Lake was materially lowered or the level unduly fluctuated. They have further pointed out that the whitefish desert spawning grounds which have been used for many years when these are rendered unfit by the lowering of lake levels, and refuse to spawn elsewhere. In view of the importance of this industry on Red Lake, it appears undesirable to lower the Lake to any such level as some of the other interests have proposed.

Although navigation on Red Lake is not of much importance at the present time, the development of Northern Minnesota as a summer playground makes it highly desirable to establish levels on Red Lake which will not be unduly prejudicial to prospective navigation and summer resort interests. If the Lake were lowered to the extent proposed by some interests, the present beautiful shores would be transformed into sandy wastes and the water's edge moved out many hundred feet, leaving pot holes behind the exposed sand bars.

### **Recommended Levels**

The levels herein recommended for Red Lake were determined by a careful consideration of all interests affected. They are believed to permit the most advantageous use of the water of Red Lake and of the lands bordering the Lake and the Red Lake River. The recommendation is concisely stated in the preceding summary and will not be further discussed here.

Frequency curves of natural and of regulated lake levels are shown on Sheet III.

## **REGULATION OF OUTFLOW**

### **Natural Regulation**

Red Lake in a state of nature has a great equalizing effect on the flow of Red Lake River. During early spring, only about

one-quarter as much flood water flows down Red Lake River above the mouth of Thief River as would pass were it not for the natural retarding effect of the Lake. The maximum natural outflow from the Lake represents only about 1 second foot per square mile, whereas the flood flow at Crookston in 1916 represented nearly 3 second feet per square mile and occurred at a time when the outflow from Red Lake was less than half a second foot per square mile. It follows, then, that the floods on the lower Red Lake River must be attributed, not to Red Lake itself, but primarily to the character of Red Lake River and the adjacent lands. However, the natural reservoir effect of Red Lake can be augmented by proper artificial control. Studies of such control must be based on mass curves of inflow into the Lake and not of outflow from the Lake, as is often done, otherwise the natural reservoir effect of the Lake will be disregarded.

### Regulation for Drainage and Flood Control

It is proposed to build a dam with sluice gates in the Red Lake River near the outlet of the Lake for the purpose of controlling all the levels and the outflow. It is further proposed to greatly enlarge the outlet and to improve the channel of Red Lake River by deepening it and cutting off bends so as to provide an outlet for drainage ditches to be constructed for the purpose of draining lands lying on both sides of Red Lake River, below the outlet of the Lake. This outflow channel, which will have a capacity of 1,000 cubic feet per second at considerably less than bank-full stage, will carry off the flood water from the drained lands lying on both sides of the river when the dam at the outlet of the Lake is closed. After this flood water has run off and the lower river has fallen, the flood water temporarily stored in Red Lake—if it has been necessary to store above the level of 1,174—shall be wasted at a rate which, including the inflow from drainage ditches will never exceed 1,500 cubic feet per second. For the temporary storage of flood water while the improved channel is carrying off the water contributed by the drainage ditches, there will be required less than one foot depth on Red Lake.

Early spring floods can be anticipated by a study of the records of fall and winter precipitation and storage capacity shall be provided in the reservoir for such flood water before the spring break-up.

Summer rains will seldom produce rates of inflow that will necessitate storing flood water for more than a few inches depth on the Lake. The worst summer rainstorm on record for Minnesota, that of July 20, 1909, centering at Beaulieu, where 10.75 inches fell in one day, would have resulted in an average precipitation on the Red Lake basin of about 6 inches, had it centered on the Lake. Such an exceptional rainstorm, which probably will not recur within an area of 2,000 square miles more often, on an average, than once in 100 years or more, would have raised the level of Red Lake about one foot. The exceptional storm of July 1, 2 and 3, 1919, which centered at Warroad, Minnesota, where 8.97 inches of rain fell in three days, resulted in an average precipitation on the Red Lake drainage basin of about 4.5 inches. No record of the resulting rise in lake level is available.

### **Regulation for Municipal Purposes**

During normal years the requirements of municipalities for water supply and sewage disposal purposes will be amply provided for. It is only during periods of extreme low water that their needs will have to be considered as affecting the proposed control.

During dry periods the rainfall on the lake surface plus the runoff from the land area is insufficient to supply even the evaporation from the Lake. During dry summer months evaporation alone will at times lower the lake level two or three inches in a single month.

Whenever continued drought has depleted the available supply of stored water to elevation 1,172, the outflow shall be limited to a rate of 150 cubic feet per second, or such lower rate as may be required for municipal water supply and sewage disposal purposes; provided, however, that such lower rate of controlled outflow shall never be less than the rate which would prevail under the existing climatic conditions if no artificial regulation had been in force.

In this connection it is interesting to note that a flow of 150 cubic second feet can be maintained for 1 year on 0.4 feet in depth on Red Lake—equivalent to the evaporation loss during a dry summer month. During the dry years of 1910-1913 the flow at Crookston was less than this for 13 months, dropping to a minimum of less than 50 cubic second feet during the winter of 1912.

## Regulation for Navigation of Red Lake River

During times when there is a heavy runoff from the local drainage area below the outlet of Red Lake, it will be necessary to close the controlling dam entirely in order to permit the drainage ditches to discharge freely into the improved channel. The control works must also be closed during the summer whenever it is necessary to conserve water for beneficial use on the river below. Such a condition will at times extend over several months. It follows, therefore, that at such times there may be relatively little water in the improved channel immediately below the control dam and consequently navigation of that portion of the river may be interrupted. The control works can, of course, be opened for a day or two whenever necessary to provide water for boats desiring to navigate the upper river.

Such complete shutting off of the flow from Red Lake, when the river below is in flood, was evidently contemplated by the United States Engineers in their report, published in House Document No. 61, previously referred to. (See Page 24, Paragraph 7, Water Power). This matter should be kept clearly in mind when considering the effects of the proposed improvement on the possible navigation of the Upper Red Lake River. The discharge of water from Red Lake for the purpose of maintaining navigable stages immediately below the control dam at all times would completely nullify the drainage and flood control features of the project in some years, prevent the beneficial use of the waters of the Lake for other purposes in others, and result in draining the Lake to unprecedented levels during still other years. That the United States Army Engineers did not contemplate any navigation improvement is evidenced by the fact that they recommended participation in the project by the United States only to the extent of an appropriation of \$15,000.00 for supervision and nothing for construction. If in the future navigation develops to an extent necessitating the construction of a lock the federal government will undoubtedly provide the necessary additional structures in the public interest, as has been the policy of the government in the past.

## Regulation for Water Power Purposes

Regulation of the outflow from Red Lake solely for the benefit of drainage, flood control, navigation, fishing and summer resort interests would result in wasting a valuable natural resource—the one resource which can be conserved only by utilizing it; a natural resource which can never become exhausted, for it is being replenished every day that the sun shines. This resource is water power. Regulation of the outflow from Red Lake solely for the benefit of water power, however, would be detrimental to other interests. A method of control is here recommended which aims to provide the largest benefit to water power consistent with the drainage and flood control features of the project and the beneficial use of the waters in Red Lake for other purposes.

In general, there are two methods of controlling the outflow from a reservoir for use in water power development. The first method is that of increasing the dependable minimum flow of the stream at the point where most of the water power development takes place. Under this method, a study is made of the supply of water which has been available over a considerable period of years, covering particularly the dry years. From the available supply and the storage capacity which it is practicable to provide in the reservoir, there is computed the dependable rate of outflow; that is, the maximum rate of discharge which could have been maintained on the available inflow and storage during the most protracted period of drought on record.

Under this method of control it is impossible to specify a minimum level below which the reservoir may not be drawn, because it cannot be known just what the future inflow will be, and the outflow must be maintained on the inflow plus draft on stored water regardless of the lake stage. The predetermined, dependable rate of flow becomes the basis for the capacity of the water power plants installed on the stream. Power developed from the dependable flow becomes primary power, available at all times, indefinitely into the future, against which no auxiliary steam plant capacity need be provided, unless considered necessary to prevent interruptions in service through breaks in the lines transmitting current from the water power plant to the market. Under regulation to increase the dependable flow, the release of water from the reservoir is at all times limited to what-

ever is necessary to furnish the dependable flow at a specified point on the stream, with no excess at any time, except when water is being wasted.

The second method of controlling the outflow from a reservoir for water power purposes consists in utilizing the available storage capacity over and over as frequently as possible, storing water through the wet months of the year for use during the dry months. Under this system of regulation, the natural extreme low water flow of the stream cannot be materially increased because it is impossible to predict a series of dry years. Water power plants can economically be installed of a considerably larger capacity, however, than in the case where regulation is with a view to increasing the dependable flow. This being the case, the aim is to discharge stored water at as large a rate as is necessary to meet the requirements of the water power plants at the given time. Predictions of flow are limited to a few months in advance. In general, the aim is to use up the stored water while there is any and when it has all been drawn from the reservoir, to discharge only the natural low water inflow, maintaining the reservoir above a definite, minimum stage.

Under regulation to increase the utilizable flow, the minimum level to which the reservoir shall be drawn can be predetermined and fixed. The only condition under which further lowering may become inevitable is that of evaporation from the reservoir surface in excess of rainfall plus the inflow into the reservoir from the tributary land area.

Under the method of regulation to increase the utilizable flow, a larger aggregate amount of water can be beneficially used for power purposes than under regulation to increase the dependable flow, but larger steam plants must be provided. Moreover, less reserve flood-water storage capacity need be provided above the power reservoir because normally the power reservoir will not be full.

During the preliminary studies of this project, it appeared most desirable to regulate the outflow from the proposed Red Lake reservoir with a view to maintaining a dependable flow of 600 cubic feet per second at Crookston for power purposes. Further studies, however, led to the conclusion that regulation to increase the utilizable flow, combined with the maintenance of a low water

reserve, is more desirable. One of the primary reasons for this conclusion is the fact that for four consecutive years the natural outflow from Red Lake did not average one inch in depth on the tributary drainage basin, whereas during the high water year of 1916, the outflow represented over 6 inches depth. To maintain a reasonably large dependable rate of outflow over such a period of dry years as that between 1910 and 1914 would require drawing down the Lake to a minimum stage which would be seriously detrimental to fishing, navigation and summer resort interests. Moreover, the minimum stage to which the Lake should be drawn could not be fixed.

Charts 1-21 show what the outflow from Red Lake would have been if regulated as herein proposed. These charts also show the computed natural outflow from the Lake and the observed stream flow at Crookston. It is recognized that there are some apparent discrepancies. The natural outflow from Red Lake during an occasional month or two in winter is in excess of the flow at Crookston. This discrepancy may be due as much to the inaccuracy of the estimated winter discharge at Crookston as to the computed natural outflow from Red Lake. The records for the winter discharge at Crookston are conceded to be of a low degree of accuracy, inasmuch as they are estimated almost exclusively on the basis of climatological data. No effort has been made to reconcile such discrepancies because they have no material bearing on the conclusion drawn.

### **Beneficial Use of Available Water**

Under the system of control here recommended, the available space for storing water in Red Lake is divided into three more or less distinct portions—namely, a low water reserve of about a foot depth below 1,172, a primary reservoir between 1,172 and 1,174, and emergency flood water storage of about one foot above 1,174. The space between 1,172 and 1,174, constituting the primary reservoir, will store most of the flood water which enters the Lake. By means of this reservoir, high rates of inflow, frequently exceeding an average of 3,000 cubic feet per second for one month, will be held back and gradually discharged from the Lake at rates not exceeding 1,500 cubic feet per second, extending over a considerably longer period of time. In this primary reservoir flood water will be stored so that it can not damage the lands on

the river below, but on the contrary, will be put to beneficial use in maintaining a more uniform flow in Red Lake River.

During excessive summer rains following a winter of heavy snowfall and a wet spring, this primary reservoir can not always absorb all of the rapid flood water inflow into the Lake. Rainfall records indicate that 6 or 8 inches of rain may fall on the lake surface in two or three days, which alone will raise the Lake an equal amount. Such heavy rains will, of course, also cause heavy runoff from the land area tributary to the Lake. No one can predict just what this extreme flood inflow may some time be. For this reason, my recommendations contemplate storing flood water above elevation 1,174 during the extreme conditions which can not be foreseen. In other words, about a foot of reservoir space has been provided above 1,174 for emergency flood water storage. Should unprecedented conditions prevail, the control works can also be opened wide.

Similarly, no one can predict just how dry the summer months may sometime be. Occasionally the evaporation from the Lake surface exceeds the rainfall on the lake area plus the runoff into the Lake from the land area. At such times the Lake would necessarily fall, even though the control works were closed off entirely. To meet this condition, a low-water reserve of about one foot depth below 1,172 is provided to supply excessive evaporation and to furnish water for municipal purposes during extreme droughts.

Although no records of outflow from Red Lake and inflow into the Lake are available, I have computed these factors from climatological and other data covering the entire period from 1899 to 1921.

No rational study of the beneficial use of the waters of Red Lake nor of the use of the Lake for flood prevention purposes could be made without this information. The computed monthly mean net inflow into Red Lake is plotted in the form of a mass curve, shown on Sheet IV. A similar curve is shown which was computed from the outflow as it would have been regulated in the interest of drainage, flood control, water power, etc.

The average inflow into Red Lake for the period 1899 to 1921 was 445 cubic feet per second. In my judgment, water power plants on Red Lake River at Crookston can economically utilize

an average of about 1,250 cubic feet per second distributed through the year as shown in Table IX. Such plants would utilize about 90 per cent or over of the total outflow from Red Lake.

The extent to which the stream flow at Crookston can be improved by the proposed regulation for utilization in power development is shown on Charts 1 to 21, in Table IV and in Table X. If the proposed regulation had been in force during the past 21 years, the spring and summer flow at Crookston would, on an average, have been reduced as follows: April, 462 c. s. f.; May, 566 c. s. f.; June, 535 c. s. f.; July, 372 c. s. f.; August, 165 c. s. f.; September, 18 c. s. f. The fall and winter flow at Crookston would have been increased as follows: October, 32 c. s. f.; November, 266 c. s. f.; December, 492 c. s. f.; January, 599 c. s. f.; February, 621 c. s. f.; March, 451 c. s. f.

## BENEFITS

Since the benefits to agricultural lands will be determined by a board of appraisers, no effort has been made here to estimate them; neither has the benefit to municipalities been estimated. It would appear, however, that some fundamental facts and principles should be laid down to guide the appraisers in determining the portion of the cost of the proposed project which should be assessed against the water power interests.

Two factors should receive consideration: first, the increased cost of the project to provide water power benefits, and second, the actual benefits conferred upon water power by the entire improvement.

In this project the cost of the control works is increased by about \$8,000.00, to provide facilities for controlling the outflow from the Lake in the interest of water power development. However, regulation for water power alone would necessitate a control dam, and some channel improvement below the Lake if the maximum and minimum lake levels adopted under regulation were equal to those prevailing in a state of nature. The provision of drainage outlets to the lands bordering Red Lake River necessitates the provision of a greatly enlarged channel in this stream. It also makes a dam at the outlet necessary to control the flood waters and permit the drainage waters to occupy the improved channel during heavy rains. In consequence of the channel im-

provement, the lake level can be lowered about  $1\frac{3}{4}$  feet to facilitate the drainage of lands bordering Red Lake itself and without serious detriment to other interests. If the natural maximum lake stage of about 1,176.5 were adopted as the maximum under regulation and the minimum were as here proposed, the benefits to water powers would be increased about fifty per cent and substantially the entire outflow from Red Lake would be utilized. No larger plants would be necessary. Such regulation, however, would result in no benefit to the agricultural lands around Red Lake, and the greater range in level would be somewhat detrimental to navigation and summer resort interests and to the fishing industry. The exact evaluation of these several factors is impossible.

Drainage and flood control on the one hand and regulation of stream flow in the interest of water power development on the other, both require control works and jetties. On this basis the cost of these works themselves might be equally distributed between these two interests.

On the basis of the equitable distribution of cost among the interests in whose behalf the expenditure is incurred, and with due regard to the total cost of a project designed solely to benefit any one given interest but without consideration of benefits conferred by the proposed improvement, the water power interests should pay about \$150,000.00 plus part of the annual operation and maintenance expense.

The benefits which will accrue to water power from the proposed improvement are those which result from the savings affected through the sale of electric energy generated by water power as against steam power.

The portion of the stream flow which can be economically utilized for the development of power at any given site largely determines the value of that site. The proposed regulation of Red Lake will materially increase the utilizable flow of Red Lake River and thus it will increase the value of every developed and undeveloped power site. Plants now in operation, or about to be constructed will evidently benefit in larger measure than those sites which may not be developed for some years to come.

The data of Table X indicate that the proposed regulation of Red Lake will increase the flow at Crookston which can economically be utilized for the development of water power by an aver-

age of 112 cubic feet per second. This is equivalent to an average increase of about 2,000 continuous horsepower for the entire utilizable fall of the stream.

On the basis of raw water being worth \$10.00 per horsepower per year in the locality under consideration, as an average value, to existing water power plants, to those now in contemplation, and to those sites which will probably not be developed for some years to come, the regulation of Red Lake will benefit water power to the extent of \$20,000.00 a year. This represents 8 per cent on a capital investment of \$250,000.00, or in other words, an increase in the capital value of both developed and undeveloped power sites on Red Lake River of that amount.

The value of raw water in any given locality is dependent mainly upon the relative costs of producing electrical energy by steam and by water power.

Regulation of Red Lake will increase the value of the power sites on Red Lake River because it will increase their earning capacities. Plants now in operation can almost immediately take advantage of the increased stream flow at Crookston. The increased earnings represent an increase in the capital value of these plants. Similarly, even though in lesser degree, the value of the undeveloped power sites is also increased. The increased value of water power sites, because of increased earning capacity resulting from river regulation, is fairly comparable with the increased value of agricultural lands because of increased crop producing ability resulting from drainage. The benefits assessed against agricultural lands express increased earning capacity in terms of increased capital value.

Converting the increased utilizable stream flow into power which can be developed under the total utilizable fall gives an average annual increase of about ten million kilowatt hours of power transmitted to the point of distribution. Taking into consideration the fact that substantially all the power must be stabilized by an auxiliary steam power plant, held in reserve for use during extreme low water years when regulation will add practically nothing to the natural stream flow, this additional power is probably worth about \$50,000.00 a year, on the basis of the total utilizable fall. This represents 8 per cent on a capital investment of \$625,000.00.

The question of the extent to which the water power interests on Red Lake will benefit by the proposed regulation should receive further study as a part of the appraisal work. The portion of the cost finally assessed against the water powers should bear the same ratio to benefits found as in the case of agricultural lands.

Respectfully submitted,

ADOLPH F. MEYER,

Consulting Engineer.

## ESTIMATED COST OF CONTROL WORKS, OUTLET OF RED LAKE

4,960 yards excavation.....	\$5,000.00
2,560 lineal feet round piling in place.....	1,360.00
11,200 feet B. M. sheet piling in place.....	784.00
4,300 feet B. M. back lash wall in place.....	323.00
1,512 cubic yards concrete in place.....	18,180.00
15,300 pounds reinforcing steel in place.....	690.00
12,400 feet B. M. lumber for stop logs, fishway, etc....	970.00
6 sluice gates, 6 sets of racks, stop log hoist, in- cluding track and miscellaneous steel.....	4,800.00
110 cubic yards rip rap in place.....	770.00
Back fill .....	750.00
Cofferdams and pumping.....	2,500.00
	<hr/>
	\$36,127.00
Engineering and contingencies.....	3,500.00
Contractor's profit.....	3,633.00
Construction camp, other temporary structures, and equipment shrinkage.....	3,000.00
	<hr/>
	\$46,260.00

## OTHER COSTS

Right-of-way for control works and approach channel..	\$800.00
One mile of detour road.....	1,500.00
18 miles of telephone line.....	2,500.00
Caretaker's dwelling, shop, etc.....	7,000.00

TABLE I

AVAILABLE STREAM FLOW DATA—RED LAKE RIVER  
DRAINAGE BASIN

A.

Station	Drainage Area	Available Data
Red Lake River above mouth of Thief River.	2,400 sq. mi. ....	May, 1899, to Aug. 1901
Red Lake River below mouth of Thief River.	3,430 sq. mi. ....	During open season, 1910 to 1919, inclusive.
Red Lake River at Crookston .....	5,320 sq. mi. ....	During open season, 1901 to 1919, inclusive.
Thief River near Thief River Falls. ....	1,010 sq. mi. ....	During open season, 1909 to 1917, inclusive.

AVAILABLE RECORDS OF RED LAKE LEVEL

B.

Single Instrumental Determinations of Lake Level Made in 1907, 1911, 1913, 1917, 1920 and 1921. See Table V.

Readings Taken by W. M. Everts, Ditch Engineer, Beltrami County, Minnesota. Gage Located at Washkish, in Upper Red Lake. June, 1910, to September, 1920. See Table VI.

Readings Reported by A. C. Goddard for Period from April, 1908, to July 19, 1921. A summary of these readings was published in the First Annual Report of the Board of Directors of the Red Lake Drainage and Conservancy District, October, 1921. Even after changing the decimal, these readings represent so many physical impossibilities as to make them quite unreliable. They were not used in this report.

Readings of Lake Gage Established at Red Lake Agency, July 20, 1921, by Minnesota Department of Drainage and Waters. A. C. Goddard, Gage Reader. See Table VII.

Readings of Lake Gage Established at Washkish, in Upper Red Lake, September, 1921, by Minnesota Department of Drainage and Waters. David Lyon, Gage Reader. See Table VIII.

## AVAILABLE METEOROLOGICAL DATA

### C.

Precipitation and Temperature, Red Lake, Minnesota. Observed by A. C. Goddard for the United States Weather Bureau, March 1, 1908, to date.

Precipitation and Temperature, Kelliher, Minnesota. Observed by A. Gilmour, for the United States Weather Bureau, 1909 and part of 1910.

Precipitation and Temperature Data at Several Stations at Various Distances Removed from the Basin Tributary to Red Lake.

TABLE II—DISCHARGE DATA AND COMPUTATIONS

Year and Month.	Red Lake River Below Thief River	Thief River.	Difference Column 1 Minus Column 2.	Run-off per Square Mile, Thief River.	Run-off per Square Mile, Clearwater.	Average Run-off per Square Mile.	Com- puted Run-off From 470 Square Miles.	Column 3— Column 7, Discharge From Red Lake.	Com- puted Outflow From Red Lake.
1909									
July .....	1380	936	444	.440	.389	.415	195	249	450
August .....	948	552	396	.392	.908	.650	305	91	500
September .....	967	667	300	.297	.295	.296	139	161	475
October .....	926	563	363	.359	.292	.326	153	210	550
November .....	828	538	290	.287	.214	.251	118	172	550
December .....	700	500	200	.198	.199	.199	94	106	500
1910									
January .....	530	100	430	.099	.168	.134	63	367	400
February .....	530	45	485	.045	.088	.067	32	453	375
March .....	2200	330	1870	.327	.508	.418	198	1672	400
April .....	2260	1150	1110	1.14	.992	1.07	503	607	625
May .....	1330	438	892	.434	.247	.341	160	731	750
June .....	786	160	626	.158	.091	.125	59	567	500
July .....	406	108	298	.107	.027	.067	32	266	350
August .....	222	44	178	.044	.028	.036	17	161	200
September .....	210	8	202	.008	.031	.020	9	192	175
October .....	185	0	185	.0	.035	.018	8	176	150
November .....	137	0	137	.0	.037	.019	8	128	130
December .....	138	0	138	.0	.038	.019	8	129	125
1911									
January .....	125	0	125	.0	.034	.017	8	117	115
February .....	95	0	95	.0	.034	.017	8	87	90
March .....	150	12	138	.012	.042	.027	13	125	100
April .....	375	46	329	.046	.181	.114	54	275	150
May .....	290	7	283	.007	.070	.039	18	264	120
June .....	624	10	614	.010	.137	.074	35	579	130
July .....	64.4	1.3	63	.001	.024	.013	6	57	70
August .....	30.8	0.2	30.6	.0	.052	.026	12	18	20
September .....	26.0	0.5	25.5	.0	.035	.018	8	17	15

TABLE II—DISCHARGE DATA AND COMPUTATIONS—Continued

Year and Month.	Red Lake River Below Thief River	Thief River.	Difference		Run-off per Square Mile, Thief River.	Run-off per Square Mile, Clearwater.	Average Run-off per Square Mile.	Com- puted Run-off From 470 Square Miles.	Column 3— Column 7, Discharge From Red Lake.	Com- puted Outflow From Red Lake.
			Column 1 Minus Column 2.	Column 1						
1912										
October	32.8	1.1	31.7	.001	.035	.018	8	23	20	
November	13.8	0.2	13.6	.0	.0	.0	0	14	15	
December	9.0	0.0	9.0	.0	.0	.0	0	9	10	
1913										
January	4	0.0	4	.0	.0	.0	0	4	5	
February	4	0.0	4	.0	.0	.0	0	4	5	
March	7	0.5	6.5	.0	.0	.0	0	6	10	
April	85.5	8.7	76.8	.009	.0	.009	4	73	40	
May	93.1	4.8	88.2	.005	.0	.005	2	86	60	
June	98.3	2.5	95.8	.003	.0	.003	1	94	70	
July	162	2.2	159.8	.002	.0	.002	1	159	125	
August	160	1.4	158.6	.001	.0	.001	0	158	140	
September	259	24.3	234.7	.024	.0	.024	11	223	175	
October	314	41.4	272.6	.041	.279	.160	8	225	225	
November	280	32.7	247.3	.032	.001	.407	22	225	225	
December	125	14.0	211.0	.014	.046	.030	14	197	175	
1913										
January	86	10	76	.01	.027	.014	7	69	75	
February	84	9	75	.009	.022	.016	8	67	70	
March	78	7	71	.007	.025	.016	8	63	65	
April	1370	657	713	.650	.985	.818	385	328	250	
May	413	112	301	.111	.230	.171	80	221	220	
June	293	27	266	.027	.092	.060	28	239	210	
July	221	13	208	.012	.076	.044	21	187	190	
August	169	8	160	.008	.065	.037	17	144	145	
September	156	10	146	.009	.067	.038	18	129	135	
October	209	21	188	.021	.164	.092	43	145	140	
November	207	25	182	.025	.074	.050	24	158	140	
December	111	15	96	.015	.050	.033	16	80	115	

TABLE II—DISCHARGE DATA AND COMPUTATIONS—Continued

Year and Month.	Red Lake River Below Thief River	Thief River.	Difference Column 1 Minus Column 2.	Run-off per Square Mile, Thief River.	Run-off per Square Mile, Clearwater.	Average Run-off per Square Mile.	Com- puted Run-off From Square Miles.	Column 3— Column 7, Discharge From Red Lake.	Com- puted Outflow From Red Lake.
1914									
January	125	5	120	.005	.042	.023	11	109	100
February	102	1	101	.001	.055	.028	13	88	90
March	215	3	212	.003	.057	.030	14	198	150
April	457	146	311	.145	.235	.190	89	222	220
May	467	132	335	.131	.413	.272	128	207	210
June	574	176	398	.174	.658	.416	195	203	200
July	329	69	260	.069	.468	.269	127	133	175
August	225	29	196	.029	.136	.083	39	157	160
September	297	51	246	.050	.151	.101	47	199	165
October	415	91	323	.091	.135	.113	53	271	225
November	268	84	185	.083	.107	.095	45	140	200
December	275	63	212	.062	.043	.053	25	187	190
1915									
January	215	42	173	.04	.38	.039	18	155	185
February	370	33	337	.033	.038	.355	17	320	180
March	524	59	465	.058	.046	.052	24	441	240
April	708	293	415	.29	.515	.40	188	227	310
May	762	247	515	.245	.376	.311	146	369	350
June	1140	550	590	.545	.754	.650	305	285	400
July	1280	545	735	.540	1.046	.793	373	362	400
August	491	88	403	.087	.118	.103	48	355	350
September	445	32	413	.032	.076	.054	25	388	225
October	510	46	464	.050	.09	.07	33	431	200
November	406	44	362	.04	.07	.055	26	336	200
December	475	9	466	.0	.06	.03	20	446	225
1916									
January	368	2	366	.0	.05	.025	12	354	225
February	373	0	372	.0	.06	.030	14	358	250
March	418	2	416	.0	.05	.025	12	404	275

TABLE II--DISCHARGE DATA AND COMPUTATIONS--Continued

Year and Month.	Red Lake River Below Thief River	Thief River.	Difference		Run-off per Square Mile, Thief River.	Run-off per Square Mile, Clearwater.	Average Run-off per Square Mile.	Com- puted Run-off From 470 Square Miles.	Column 3— Column 7, Discharge From Red Lake.		Com- puted Outflow From Red Lake.
			Column 1 Minus Column 2.	Column 1 Minus Column 2.					Column 3— Column 7, Discharge From Red Lake.	Column 3— Column 7, Discharge From Red Lake.	
April	3580	2060	1520	2.04	1.6	1.82	856	664	500	500	
May	3280	1020	2260	1.01	1.07	1.04	488	1772	1050	1050	
June	2320	245	2750	0.24	.60	.42	198	1877	1400	1400	
July	1890	104	1786	.10	.46	.28	132	1654	1300	1300	
August	1110	246	864	.24	.10	.17	80	784	900	900	
September	1300	372	928	.37	.10	.235	110	818	750	750	
October	1040	160	880	.158	.091	.125	59	821	650	650	
November	798	109	689	.108	.049	.079	37	652	550	550	
December	524	13	511	.013	.044	.029	14	497	550	550	
1917											
January	300	295	5	.003	.053	.029	14	9	500	500	
February	389	386	3	.003	.053	.028	13	10	450	450	
March	647	643	4	.004	.083	.044	21	17	450	450	
April	2440	1609	831	.821	.477	.649	305	526	550	550	
May	1040	918	122	.121	.163	.142	67	55	400	400	
June	653	620	33	.032	.065	.049	23	10	425	425	
July	436	417	19	.019	.051	.035	16	3	350	350	
August	223	221	2	.002	.044	.023	11	9	250	250	
September	218	214	4	.004	.053	.029	14	10	150	150	
October	215								155	155	
November	240								125	125	
December	120								100	100	

TABLE III--COMPARATIVE ESTIMATES OF OUTFLOW  
FROM RED LAKE

Date.	United States Engineers H. D. No. 61. c. s. f.	Consulting Engineer Red Lake Drainage and Con- servancy District. Outflow c. s. f.
1913.		
March .....	45	65
April .....	1,290	250
May .....	279	220
June .....	141	210
1916.		
March .....	265	275
April .....	2,670	500
May .....	1,725	1,050
June .....	1,220	1,400
July .....	1,070	1,300
August .....	566	900

TABLE IV—SUMMARY OF HYDROLOGICAL COMPUTATIONS, RED LAKE DRAINAGE BASIN—  
AREA, 1,950 SQUARE MILES

	Year and Month.	Temper- ature Deg. F.	Precipi- tation, Inches.	Natural Inflow c. f. s.	Natural Outflow c. f. s.	Natural Lake Level.	Regulated Outflow.	Regu- lated Lake Stage.
1901	January	4.0	.25	100	740	1176.20	1050	1173.90
	February	2.4	.37	100	730	76.10	1000	73.70
	March	20.3	1.70	500	720	75.95	700	73.60
	April	43.0	2.20	2500	1150	76.15	0	73.87
	May	56.8	.75	1000	1300	76.25	0	74.21
	June	60.8	6.50	2000	1400	76.30	0	74.53
	July	70.0	4.00	800	1200	76.25	0	74.82
	August	66.0	2.75	200	1100	76.05	300	74.90
	September	53.8	2.25	100	900	75.90	500	74.85
	October	46.8	3.70	1500	950	75.90	700	74.89
	November	24.7	.50	150	875	75.80	1200	74.86
	December	9.6	.50	350	775	1175.70	1500	1174.63
1902	January	10.5	.17	150	650	1175.60	1500	1174.35
	February	12.4	.52	200	575	75.50	1500	74.07
	March	29.7	1.00	100	500	75.40	800	73.84
	April	39.0	1.40	1000	550	75.45	0	73.86
	May	54.2	4.00	1200	625	75.55	0	74.10
	June	59.4	2.75	200	600	75.50	0	74.25
	July	67.6	4.25	400	575	75.45	500	74.26
	August	63.1	5.00	1400	650	75.66	700	74.32
	September	53.2	1.25	—400	600	75.45	800	74.27
	October	47.8	1.80	1000	600	75.50	500	74.20
	November	28.0	.90	150	550	75.45	500	74.22
	December	8.0	.70	325	500	1175.40	1200	1174.08
1903	January	4.0	.60	250	450	1175.35	1400	1173.86
	February	5.7	.70	250	425	75.30	1100	73.65
	March	22.9	.95	400	425	75.30	800	73.51
	April	40.0	1.80	2500	600	75.50	0	73.74
	May	54.6	3.10	900	800	75.70	0	74.09
	June	61.6	1.90	—200	675	75.65	200	74.14
	July	65.3	1.70	—500	550	75.40	200	74.02
	August	62.0	4.20	700	400	75.35	300	74.00
	September	54.0	4.40	1050	500	75.45	0	74.15
	October	46.0	2.30	900	575	75.50	200	74.33
	November	23.1	.50	200	550	75.50	1200	74.30
	December	5.4	1.00	550	550	1175.50	1400	1174.11
1904	January	2.0	.23	200	525	1175.40	1500	1173.88
	February	1.0	.90	450	525	75.40	1500	73.63
	March	21.0	2.50	950	550	75.45	1200	73.48
	April	36.0	1.20	1800	725	75.65	0	73.65
	May	53.0	1.90	850	750	75.80	0	73.93
	June	63.0	2.60	50	700	75.65	0	74.02
	July	64.5	4.00	350	650	75.60	0	74.07
	August	61.0	1.70	—450	550	75.45	0	74.05
	September	54.0	4.00	1200	500	75.45	200	74.10
	October	46.0	1.10	—50	475	75.40	500	74.15
	November	34.0	.30	—250	425	75.30	700	74.00
	December	10.0	.70	300	400	1175.25	900	1173.83
1905	January	11.7	.50	150	375	1175.20	1200	1173.66
	February	4.2	.26	75	350	75.15	1200	73.43
	March	27.1	1.20	1150	400	75.20	900	73.34
	April	38.0	2.00	1200	475	75.35	0	73.49
	May	50.2	4.95	2900	700	75.60	0	73.93
	June	60.0	7.25	4200	1250	76.25	0	74.69
	July	66.0	5.50	1700	1700	76.60	700	75.24
	August	66.2	3.00	300	1100	76.45	1000	75.26

TABLE IV—Continued

	Year and Month.	Temper- ature Deg. F.	Precipi- tation, Inches.	Natural Inflow c. f. s.	Natural Outflow c. f. s.	Natural Lake Level.	Regulated Outflow.	Regu- lated Lake Stage.
	September	60.0	3.20	700	900	76.35	1000	75.16
	October	40.1	1.50	900	950	76.30	1200	75.10
	November	29.5	3.00	1500	1050	76.35	1500	75.07
	December	15.3	.25	700	1000	1176.35	1500	1174.98
1906	January	12.4	.95	650	950	1176.30	1500	1174.81
	February	6.6	.30	400	900	76.20	1500	74.60
	March	17.3	.53	300	800	76.10	1300	74.37
	April	45.0	1.50	1700	900	76.15	0	74.45
	May	50.6	3.10	1400	1100	76.25	0	74.78
	June	63.1	4.30	1100	1100	76.30	700	74.97
	July	68.0	2.00	—400	800	76.15	1000	74.86
	August	65.7	3.00	0	700	75.95	1000	74.61
	September	61.4	1.70	—300	625	75.80	1000	74.37
	October	43.3	1.10	100	550	75.65	1000	74.14
	November	28.2	3.00	660	600	75.60	1000	74.00
	December	7.4	1.60	790	650	1175.65	1100	73.93
1907	January	—4.0	1.20	600	700	1175.65	1200	1173.84
	February	8.0	.10	50	650	75.60	1500	73.61
	March	21.7	.60	100	650	75.45	600	73.40
	April	30.1	1.10	1400	675	75.50	0	73.50
	May	42.1	.90	880	700	75.60	0	73.75
	June	62.0	3.00	340	700	75.55	0	73.87
	July	64.4	3.40	130	650	75.50	0	73.92
	August	61.0	3.50	380	500	75.45	300	73.95
	September	52.2	2.40	300	500	75.40	300	73.96
	October	42.6	1.00	150	450	75.30	300	73.94
	November	27.9	.30	—50	400	75.20	550	73.86
	December	16.0	.40	75	400	1175.15	650	1173.74
1908	January	10.6	.19	200	350	1175.10	750	1173.62
	February	10.8	1.10	400	350	75.10	700	73.53
	March	17.4	1.10	400	350	75.10	500	73.49
	April	40.6	2.00	2600	500	75.30	0	73.76
	May	50.3	4.00	2200	750	75.65	0	74.27
	June	60.7	4.00	1100	950	75.85	200	74.61
	July	66.0	3.00	50	900	75.75	500	74.65
	August	61.4	2.30	—120	750	75.60	500	74.54
	September	59.0	2.00	—350	550	75.40	500	74.38
	October	45.0	1.20	—50	400	75.25	300	74.25
	November	30.4	1.10	200	350	75.20	300	74.21
	December	10.7	.60	390	350	1175.15	800	1174.15
1909	January	4.3	1.38	650	400	75.20	1000	74.08
	February	6.0	.13	100	400	75.15	1200	73.91
	March	21.0	.51	0	375	75.10	500	73.73
	April	30.6	1.08	1400	400	75.20	0	73.83
	May	50.6	1.72	700	500	75.35	0	74.06
	June	63.0	1.53	—525	450	75.25	0	74.08
	July	68.2	4.87	590	450	75.20	0	74.08
	August	67.4	6.45	1900	500	75.40	0	74.35
	September	58.0	2.43	—200	475	75.35	500	74.48
	October	43.2	2.20	1200	550	75.40	700	74.46
	November	30.0	1.10	350	550	75.45	1000	74.45
	December	7.2	1.60	450	500	1175.45	1500	1174.27
1910	January	10.0	.19	75	400	1175.40	1500	1174.00
	February	2.9	.45	200	375	75.35	1500	73.71
	March	37.0	.78	1000	400	75.40	0	73.67
	April	45.0	2.22	1950	625	75.55	0	73.99
	May	50.2	.80	—325	750	75.60	0	74.16
	June	68.4	1.18	—850	500	75.35	0	74.04
	July	68.2	2.50	—630	350	75.05	250	73.85
	August	64.2	.48	—1300	200	74.80	450	73.57

TABLE IV—Continued

	Year and Month.	Temper- ature Deg. F.	Precipi- tation, Inches.	Natural Inflow c. f. s.	Natural Outflow c. f. s.	Natural Lake Level.	Regulated Outflow.	Regu- lated Lake Stage.
	September	57.1	1.84	—550	175	74.55	450	73.28
	October	49.4	.68	—650	150	74.40	500	73.05
	November	22.2	.65	0	130	74.30	650	72.86
	December	9.6	.34	50	125	1174.30	800	1172.71
1911	January	— .8	1.00	225	115	1174.30	900	1172.56
	February	9.3	1.20	—150	90	74.25	900	72.38
	March	28.6	.50	—550	100	74.20	300	72.18
	April	40.2	.96	65	150	74.10	0	72.10
	May	56.8	2.40	—175	120	74.05	0	72.08
	June	60.0	3.89	440	130	74.10	0	72.11
	July	65.7	2.47	—550	70	74.00	150	72.08
	August	63.7	2.70	—1000	20	73.80	150	71.88
	September	55.4	2.16	—350	15	73.70	150	71.70
	October	43.0	.95	—400	20	73.60	150	71.59
	November	17.8	1.47	350	15	73.55	150	71.55
	December	17.2	.70	—150	10	1173.50	150	1171.57
1912	January	10.2	.21	15	5	1173.45	150	1171.55
	February	4.8	.38	110	5	73.45	150	71.53
	March	14.9	.35	10	10	73.45	150	71.51
	April	41.7	1.33	100	40	73.50	50	71.51
	May	57.2	2.15	—130	60	73.45	50	71.49
	June	62.9	1.62	—525	70	73.35	50	71.41
	July	67.8	3.18	—270	125	73.20	50	71.31
	August	61.4	4.06	350	140	73.25	50	71.31
	September	55.2	4.35	850	175	73.35	0	71.43
	October	46.6	1.13	—190	225	73.35	0	71.50
	November	32.8	.28	—290	225	73.25	100	71.44
	December	16.2	.83	200	175	1173.25	200	1171.40
1913	January	2.2	.35	120	75	1173.25	200	1171.39
	February	2.6	.61	220	70	73.25	200	71.38
	March	12.3	1.10	350	65	73.30	200	71.39
	April	46.2	1.37	1470	210	73.45	0	71.56
	May	50.2	1.90	160	240	73.60	0	71.73
	June	65.8	3.47	0	220	73.55	100	71.74
	July	64.0	4.70	300	200	73.50	150	71.74
	August	67.4	2.00	—850	145	73.45	150	71.65
	September	56.7	2.70	—50	135	73.30	150	71.53
	October	39.5	3.50	700	140	73.35	150	71.57
	November	34.5	.55	—225	140	73.35	150	71.59
	December	22.6	.04	—190	115	1173.30	150	1171.51
1914	January	10.0	1.14	450	100	1173.35	200	1171.50
	February	—2.9	.39	200	90	73.35	200	71.53
	March	21.0	1.02	350	150	73.40	200	71.54
	April	36.5	1.30	750	220	73.45	0	71.64
	May	56.4	3.32	800	210	73.55	0	71.80
	June	63.2	7.22	2600	200	74.00	0	72.17
	July	69.0	2.55	—220	175	73.90	0	72.42
	August	63.8	4.98	695	160	74.10	200	72.45
	September	59.2	3.14	150	165	74.10	250	72.49
	October	53.0	2.91	235	225	74.20	250	72.48
	November	30.2	.62	65	200	74.15	350	72.45
	December	6.6	.37	230	190	1174.15	600	1172.38
1915	January	2.0	.70	330	185	1174.20	700	1172.30
	February	19.0	.85	275	180	74.20	650	72.22
	March	23.1	.20	—65	240	74.15	400	72.13
	April	49.8	1.25	200	310	74.15	0	72.10
	May	50.6	3.00	845	350	74.20	0	72.21
	June	57.0	9.80	4125	400	74.65	0	72.74
	July	63.4	2.80	1140	400	75.15	0	73.30
	August	64.2	1.20	—830	350	75.05	100	73.32

TABLE IV—Continued

	Year and Month.	Temper- ature Deg. F.	Precipi- tation, Inches.	Natural Inflow c. f. s.	Natural Outflow c. f. s.	Natural Lake Level.	Regulated Outflow.	Regu- lated Lake Stage.
	September	57.2	2.20	—200	225	74.90	200	73.17
	October	47.4	.95	—200	200	74.80	400	73.06
	November	27.0	1.40	400	200	74.80	550	72.98
	December	14.3	.95	500	225	1174.85	550	1172.96
1916	January	—2.2	1.55	725	225	1174.95	650	1172.97
	February	3.3	.35	250	250	75.00	650	72.92
	March	17.0	1.70	800	275	75.05	300	72.93
	April	37.6	2.40	4100	500	75.50	0	73.43
	May	51.5	3.80	2800	1050	76.10	0	74.17
	June	61.2	4.00	1500	1400	76.30	0	74.63
	July	75.0	2.40	350	1300	76.20	0	74.82
	August	66.1	4.20	850	900	76.10	500	74.88
	September	54.6	2.00	100	750	76.00	800	74.84
	October	41.2	1.20	0	650	75.85	900	74.67
	November	28.7	.07	—200	550	75.70	950	74.46
	December	3.2	.90	200	550	1175.60	1000	1174.25
1917	January	—2.4	.22	50	500	1175.50	1100	1174.06
	February	—3.2	.70	100	450	75.40	1150	73.84
	March	23.6	.40	50	450	75.35	750	73.66
	April	35.4	.97	1200	550	1175.35	0	73.71
	May	49.6	.05	—200	500	75.35	0	73.82
	June	59.6	1.70	—100	425	75.20	0	73.79
	July	72.6	1.20	—1200	350	75.00	200	73.63
	August	64.7	.80	—1000	250	74.70	500	73.32
	September	57.2	2.50	—250	150	74.50	650	73.07
	October	34.4	2.10	375	125	74.50	500	72.95
	November	34.0	.21	—325	125	74.45	600	72.84
	December	—2	.36	150	100	1174.45	1000	1172.65
1918	January	—2.4	.60	250	75	1174.50	1100	1172.47
	February	7.2	.37	100	50	74.50	1100	72.27
	March	33.0	.11	—300	50	74.45	250	72.11
	April	41.4	2.00	400	50	74.45	0	72.09
	May	51.8	3.80	850	100	74.60	0	72.23
	June	63.0	1.85	—300	125	74.60	0	72.29
	July	66.8	4.51	300	125	74.60	0	72.29
	August	66.7	4.50	350	150	74.60	0	72.35
	September	51.2	.90	—600	125	74.55	0	72.32
	October	46.4	1.75	—150	100	74.45	0	72.24
	November	32.0	1.70	200	75	74.45	300	72.22
	December	17.7	1.25	400	50	1174.50	400	1172.21
1919	January	10.6	.14	—25	25	1174.50	500	1172.15
	February	7.7	.50	125	10	74.55	500	72.06
	March	20.0	.90	350	75	74.55	200	72.03
	April	41.2	.80	400	150	74.60	0	72.09
	May	56.3	3.40	600	200	74.70	0	72.20
	June	67.3	4.30	700	200	74.80	0	72.34
	July	69.6	7.60	4500	500	75.25	0	72.90
	August	65.7	4.90	1200	800	75.75	0	73.51
	September	59.1	1.50	—700	600	75.65	250	73.54
	October	35.8	1.60	50	450	75.45	400	73.40
	November	17.4	2.00	700	450	75.45	650	73.38
	December	2.5	.26	75	425	1175.45	900	1173.29
1920	January	—2.5	1.20	350	400	1175.40	1000	1173.13
	February	6.6	1.00	350	400	75.40	1000	72.99
	March	23.6	.75	1000	400	75.45	0	73.02
	April	30.0	.97	1600	700	75.60	0	73.30
	May	55.4	2.00	150	750	75.65	0	73.48
	June	61.8	3.30	250	600	75.55	0	73.52
	July	65.7	2.60	—400	500	75.40	100	73.49
	August	67.5	1.20	—1050	375	75.15	250	73.30

TABLE IV--Continued

Year and Month.	Temperature Deg. F.	Precipitation, Inches.	Natural Inflow c. f. s.	Natural Outflow c. f. s.	Natural Lake Level.	Regulated Outflow.	Regulated Lake Stage.
September	60.7	2.40	—250	250	74.95	250	73.10
October	51.0	1.12	—200	225	74.85	0	73.03
November	26.7	1.00	200	175	74.80	550	72.97
December	14.4	1.00	400	175	1174.80	800	1172.90
1921 January	10.9	.60	250	175	1174.85	900	1172.78
February	13.3	.60	520	175	74.90	900	72.67
March	20.2	1.20	700	200	75.00	300	72.67
April	43.0	1.50	500	275	75.10	0	72.77
May	54.7	3.00	1300	375	75.20	0	72.97
June	67.4	4.10	600	400	75.30	0	73.17
July	71.8	3.50	—100	400	75.25	350	73.19

TABLE IV (Concluded)

## ANNUAL SUMMARY BY HYDROLOGICAL YEARS

Year.	Temperature Means.	Precipitation Totals.	From November to October, Inclusive —Natural Inflow—		March to February, Inclusive —Natural Outflow—		
			C. F. S. Months.	Inches on 1,516 Sq. Mi.	Year.	C. F. S. Months.	Inches on 1,516 Sq. Mi.
1900-01.....	38.1	25.62	9,100	6.7	1901-02.....	11,595	8.5
1901-02.....	39.3	23.14	5,750	4.2	1902-03.....	6,625	4.9
1902-03.....	37.7	23.25	6,725	4.95	1903-04.....	8,675	4.9
1903-04.....	35.7	21.63	6,100	4.5	1904-05.....	6,450	4.8
1904-05.....	38.9	30.36	13,325	9.75	1905-06.....	11,375	8.4
1905-06.....	39.8	21.73	7,150	5.3	1906-07.....	9,175	6.75
1906-07.....	34.6	21.80	5,780	4.25	1907-08.....	6,325	4.65
1907-08.....	38.8	21.59	6,455	4.75	1908-09.....	6,650	4.9
1908-09.....	37.7	24.00	6,405	4.7	1909-10.....	5,525	4.1
1909-10.....	40.8	13.82	—280	—2	1910-11.....	3,610	2.65
1910-11.....	37.8	19.22	—2,395	—1.75	1911-12.....	660	.49
1911-12.....	38.1	20.93	520	.38	1912-13.....	1,390*	1.3
1912-13.....	38.0	22.81	2,330	1.7	1913-14.....	1,800	1.3
1913-14.....	40.5	28.56	5,595	4.1	1914-15.....	2,260	1.65
1914-15.....	39.2	23.94	5,915	4.35	1915-16.....	3,375	2.5
1915-16.....	37.2	25.95	12,375	9.1	1916-17.....	8,925	6.66
1916-17.....	35.3	11.61	—975	—72	1917-18.....	3,150	2.3
1917-18.....	38.2	20.96	725	.53	1918-19.....	985	.72
1918-19.....	40.2	28.59	7,800	5.7	1919-20.....	4,650	3.4
1919-20.....	36.6	18.80	2,575	1.9	1920-21.....	4,500	3.3
Average.....	38.12	22.42		3.71			3.89

\*Probably high on account of enlarged outlet.

TABLE V  
INSTRUMENTAL DETERMINATIONS OF LEVEL OF  
RED LAKE

Based on Redby B. M. Elevation 1,227.79, Sea Level Datum  
U. S. C. and G. S. 1912 Adj.

Date.	Level.	Where Determined.	Original Record.	Cor- rection Applied.
October 25, 1907	1174.7	Lower Lake	1175.8	—1.1
September, 1911	1173.4	Lower Lake	1174.5	—1.1
October, 1913	1173.3	Lower Lake	1174.4	—1.1
September 12, 1917	1174.30	Lower Lake	1174.04	+0.26
November 28, 1920	1174.72	Upper Lake	1174.72	.....
January 6, 1921	1174.75	Upper Lake	1174.75	.....
January 7, 1921	1174.70	Lower Lake	1174.70	.....
July 19, 1921	1175.28	Lower Lake	1175.02	+0.26
September 28, 1921	1174.78	Upper Lake	1174.78	.....

# TABLE VI

## Records of W. M. Everts, Ditch Engineer, Beltrami County, Minnesota.

"Elevations of Red Lake, Beltrami County, Minnesota. Water gage on pile of bridge at mouth of Tamarack River. Gage set from precise bench mark placed by United States Government on iron rod 70 feet north of the river on bank. Elevation of bench mark is 1182.678. The following readings denote the stage of the water in Red Lake from June 11, 1910, to date":

Date.	Elevation.		Elevations Corrected by —1.15	
June 11, 1910	1176.49	Judicial Ditch 4	1175.34	
June 20, 1910	1175.75	Judicial Ditch 4	1174.60	
April 12, 1911	1174.88	Judicial Ditch 8	1173.73	
April 14, 1911	1175.55	Judicial Ditch 8	1174.40	
Mar. 24, 1912	1174.80	Judicial Ditch 14	1173.65	
April 6, 1912	1174.80	Judicial Ditch 14	1173.65	
April 20, 1913	1175.0		1173.85	
June 24, 1913	1175.2		1174.05	
Nov. 1, 1913	1174.6		1173.45	
June 26, 1913	1175.15		1174.00	
June 28, 1914	1175.70		1174.55	
July 31, 1914	1175.72		1174.57	
Aug. 26, 1914	1175.54	7:00 P. M. Calm	1174.39	
Aug. 26, 1914	1175.60	5:00 P. M. Calm	1174.45	
Aug. 27, 1914	1175.52	6:30 P. M. Calm	1174.37	
Sept. 20, 1914	1175.55	11:00 A. M.	1174.40	West wind 4 mi. per hr.
Oct. 21, 1914	1175.65	Noon	1174.50	
June 16, 1915	1176.40		1175.25	
July 1, 1915	1177.1	3:00 A. M.	1175.95	
July 21, 1915	1177.15	Noon—South Wind	1176.00	
Sept. 3, 1915	1176.55		1175.40	
April 15, 1916	1178.00		1176.85	
May 6, 1916	1177.40		1176.25	
May 7, 1916	1178.00		1176.85	
May 8, 1916	1179.50		1178.35	Strong N. W. Wind
May 9, 1916	1177.50		1176.35	
May 24, 1916	1177.80		1176.65	
May 31, 1916	1177.90		1176.75	
June 3, 1916	1178.00		1176.85	
June 4, 1916	1178.10		1176.95	
June 10, 1916	1177.90		1176.75	
June 20, 1916	1178.00		1176.85	
July 1, 1916	1178.00		1176.85	
July 15, 1916	1177.50		1176.35	
July 20, 1916	1177.80		1176.65	
Aug. 1, 1916	1178.00		1176.85	
Aug. 10, 1916	1178.10		1176.95	
Aug. 15, 1916	1177.90		1176.75	
Aug. 30, 1916	1177.70		1176.55	
Sept. 1, 1916	1177.50		1176.35	
Sept. 7, 1916	1177.40		1176.25	
Sept. 11, 1916	1177.50		1176.35	
Oct. 1, 1916	1177.60		1176.45	
Oct. 10, 1916	1177.70		1176.55	West Wind
May 8, 1917	1177.00		1175.85	
May 25, 1917	1175.80		1174.65	
June 3, 1917	1176.50		1175.35	
June 11, 1917	1175.50		1174.35	
June 16, 1917	1175.50		1174.35	
June 24, 1917	1175.50		1174.35	
July 1, 1917	1176.20		1175.05	
Aug. 2, 1917	1176.00		1174.85	
Sept. 1, 1917	1175.50		1174.35	
Oct. 1, 1917	1175.50		1174.35	
Nov. 4, 1917	1175.40		1174.25	
April 10, 1918	1175.90		1174.75	
May 6, 1918	1176.00		1174.85	
June 5, 1918	1175.90		1174.75	
July 5, 1918	1176.80		1175.65	
Aug. 7, 1918	1175.70		1174.55	
July 3, 1919	1177.30		1176.15	
July 20, 1919	1176.80		1175.65	Calm
Sept. 14, 1919	1177.50		1176.35	Wind
Sept. 15, 1919	1177.40		1176.25	Wind
Oct. 3, 1919	1177.10		1175.95	Wind
Aug. 26, 1920	1177.20		1176.05	Calm
Sept. 26, 1920	1177.30		1176.15	

# TABLE VII

## READINGS OF LAKE GAGE AT RED LAKE AGENCY, JULY, 1921, TO DATE

A. C. Goddard, Observer

Date	Elevation	Notes
July 25, 1921	1175.1	"Having heavy rain; will take it again after the storm."
Aug. 1, 1921	1174.9	"Precipitation since last reading, 1.83."
Aug. 15, 1921	1171.8	"Lake has been too rough the past week for a reading until this morning."
Aug. 24, 1921	1174.7	"Precipitation since last reading, 0.14."
Sept. 12, 1921	1174.5	"Precipitation since last reading, 1.30."
Sept. 15, 1921	1174.8	
Sept. 26, 1921	1174.4	"Precipitation since last reading, 1.03."
Oct. 12, 1921	1174.3	"Precipitation since last reading, 0.00."
Oct. 20, 1921	1174.3	"Precipitation since last reading, 0.00."
April 1, 1922	1174.6	
April 14, 1922	1174.3	Battle River
April 15, 1922	1174.5	Agency
April 26, 1922	1174.5	
May 2, 1922	1174.9	
May 4, 1922	1175.0	Calm
May 5, 1922	1174.9	Light South Wind
May 6, 1922	1174.95	Light Northwest Wind
May 7, 1922	1175.0	Light Northeast Wind
May 8, 1922	1175.0	Calm
May 11, 1922	1175.0	Light West Wind
May 12, 1922	1174.9	Light South Wind
May 13, 1922	1175.1	Light Southeast Wind
May 14, 1922	1175.1	Light Northeast Wind
May 15, 1922	1175.2	
May 16, 1922	1175.1	Light South Wind
May 17, 1922	1175.2	Light Southeast Wind
May 18, 1922	1175.4	Strong Northwest Wind
May 19, 1922	1175.1	Light Northeast Wind
May 20, 1922	1175.2	Calm

TABLE VIII  
 READINGS AT LAKE GAGE AT WASHKISH,  
 SEPTEMBER, 1921, TO DATE

D. G. Lyon Observer

Date	Elevation	Date	Elevation	Notes
Sept. 28, 1921	1174.8			
April 7, 1922	1174.3	May 21, 1922	1175.5	Southeast Wind
April 8, 1922	1174.4	May 22, 1922	1175.5	South Wind
April 9, 1922	1174.6	May 23, 1922	1175.5	Northwest Wind
April 10, 1922	1174.7	May 24, 1922	1175.4	Northeast Wind
April 11, 1922	1174.8	May 25, 1922	1175.4	Northeast Wind
April 12, 1922	1174.8	May 26, 1922	1175.4	East Wind
April 13, 1922	1174.7	May 27, 1922	1175.4	Southwest Wind
April 14, 1922	1174.7			
April 15, 1922	1174.8			
April 16, 1922	1174.9			
April 17, 1922	1175.0			
April 18, 1922	1175.0			
April 19, 1922	1175.0			
April 20, 1922	1175.0			
April 21, 1922	1175.0			
April 22, 1922	1175.0			
April 23, 1922	1175.0			
April 24, 1922	1175.2			
April 25, 1922	1175.2			
April 26, 1922	1175.2			
April 27, 1922	1175.2			
April 28, 1922	1175.2			
April 29, 1922	1175.2			
April 30, 1922	1175.2			
				Notes
May 1, 1922	1175.2			Strong South Wind
May 2, 1922	1175.2			Southwest Wind; Rain from 3:00 P. M. to 4:00 A. M. ( $\frac{1}{4}$ inch)
May 3, 1922	1175.3			Light West Wind
May 4, 1922	1175.25			Light West Wind
May 5, 1922	1175.25			West Wind
May 6, 1922	1175.2			
May 7, 1922	1175.2			Light West Wind
May 8, 1922	1174.8			Northeast Wind. Rain all day and part of night.
May 9, 1922	1175.2			Light East Wind
May 10, 1922	1175.2			Light East Wind
May 11, 1922	1175.2			Light South Wind
May 12, 1922	1175.5			South Wind
May 13, 1922	1175.4			Southwest Wind

TABLE IX  
IMPROVED STREAM FLOW AT CROOKSTON, RESULT-  
ING FROM REGULATION OF RED LAKE

Change in Total Flow (The Minus Sign Indicates a Decrease)

	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911
Jan.	310	850	950	975	825	550	500	400	600	1100	785
Feb.	270	925	675	975	850	600	850	350	800	1125	810
Mar.	—20	300	375	650	500	500	—50	150	125	—400	200
Apr.	—1150	—550	—600	—725	—475	—900	—675	—500	—400	—625	—150
May	—1300	—625	—800	—750	—700	—1100	—700	—750	—500	—750	—120
June	—1400	—600	—475	—700	—1250	—400	—700	—750	—450	—500	—130
July	—1200	—75	—350	—650	—1000	200	—650	—400	—450	—100	80
Aug.	—800	50	—100	—550	—100	300	—200	—250	—500	250	130
Sept.	—400	200	—500	—300	100	375	—200	—50	25	275	135
Oct.	—250	—100	—375	25	250	450	—150	—100	150	350	130
Nov.	325	—50	650	275	450	400	150	—50	450	520	135
Dec.	725	700	850	500	500	450	250	450	1000	675	140
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	Av.
Jan.	145	125	100	515	425	600	1025	475	600	725	599
Feb.	145	130	110	470	400	700	1050	490	600	725	621
Mar.	140	135	50	160	25	300	200	125	—400	100	150
April	10	—210	—220	—310	—500	—550	—50	—150	—700	—275	—462
May	—10	—240	—210	—350	—1050	—500	—100	—200	—750	—375	—566
June	—20	—120	—200	—400	—1400	—425	—125	—200	—600	—400	—535
July	—75	—50	—175	—400	—1300	—150	—125	—500	—400	—50	—372
Aug.	—90	5	40	—250	—400	250	—150	—800	—125		—165
Sept.	—175	15	85	—25	50	500	—125	—350			—18
Oct.	—225	10	25	200	250	375	—100	—50	—225		32
Nov.	—125	10	150	350	400	475	225	200	375		266
Dec.	25	35	410	325	450	900	350	475	625		492

TABLE IX (Concluded)

Increase in Utilizable Flow\*

(The Minus Sign Indicates a Decrease; the Blank Indicates No Change)

	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911
Jan.	300	800	600	300	800		500	400	600	750	785
Feb.	270	850	650	400	850	130	850	350	800	750	810
Mar.							—50	150	125		200
April											—150
May											—120
June					—170				—450	—410	—130
July			—350				—130	—60		—100	80
Aug.	—70		—100	—500			—200	—110		250	130
Sept.	—200	120	—260	—300			—200	—20		275	135
Oct.		—100		25		317	—150	—100		350	130
Nov.	230	—50	80	275		400	150	—50	10	520	135
Dec.	600	500	10	440		450	250	450	500	675	140
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	Av.
Jan.	145	125	100	515	425	600	1025	475	600	725	503
Feb.	145	130	110	470	400	700	1050	490	600	725	563
Mar.	140	135	50	160	25	300	200	125	0	100	80
April	10			—120			—50			—275	—28
May	—10	—240	—180	—60		—110	—100	—200	—300	—375	—80
June	—20	—120				—425	—125	—200	—500	—250	—135
July	—75	—50	—175			—150	—125		—400	—50	—90
Aug.	—90	5	40	—250		250	—150		—125		—48
Sept.	—175	15	85	—25		500	—125	—350			—26
Oct.	—225	10	25	200	210	375	—100	—50	—225		35
Nov.	—125	10	150	350	400	475	225	200	375		190
Dec.	25	35	410	325	450	900	350	475	625		380

\*This is based on the assumption that water power plants can utilize water during the year at the following rates:

Jan.	1500	April	1150	July	1000	Oct.	1300
Feb.	1450	May	1050	Aug.	1050	Sept.	1450
Mar.	1300	June	1000	Sept.	1150	Dec.	1500

# TABLE X

## COMPILATION OF USEFUL DATA FOR COMPUTATIONS

Area of Red Lake Drainage Basin—1,950 square miles

Area of Red Lake Water Surface

At Elevation 1171.5—11.8 billion square feet—423.0 square miles.

At Elevation 1172.5—12.0 billion square feet—430.5 square miles.

At Elevation 1173.5—12.1 billion square feet—434.0 square miles.

At Elevation 1174.5—12.3 billion square feet—441.5 square miles.

One Inch on Red Lake Drainage Area (1,950 square miles) equals:

4.53 billion cubic feet.

1748.0 cubic feet per second for 1 month

575.0 cubic feet per second for 3 months

287.5 cubic feet per second for 6 months

143.75 cubic feet per second for 1 year

One Inch on Land Area Tributary to Red Lake (1,516 square miles) equals:

3.52 billion cubic feet.

1358.8 cubic feet per second for 1 month

446.7 cubic feet per second for 3 months

223.4 cubic feet per second for 6 months

111.7 cubic feet per second for 1 year

One Foot Depth on Red Lake at Elevation 1,173.5 equals:

12.1 billion cubic feet.

4670.0 cubic feet per second for 1 month

1535.0 cubic feet per second for 3 months

767.5 cubic feet per second for 6 months

383.75 cubic feet per second for 1 year

One Inch Depth on Red Lake at Elevation 1,173.5 equals:

1.01 billion cubic feet.

389.2 cubic feet per second for 1 month

127.92 cubic feet per second for 3 months

63.96 cubic feet per second for 6 months

31.98 cubic feet per second for 1 year

100 cubic feet per second for 1 month equals:

.259 billion cubic feet

.0214 feet depth on Red Lake (at Elevation 1173.5)

.0573 inches depth on Red Lake Drainage Area

1,000 cubic feet per second for 1 month equals:

2.59 billion cubic feet

.214 feet depth on Red Lake (at Elevation 1173.5)

.573 inches depth on Red Lake Drainage Area

100 cubic feet per second for 3 months equals:

.788 billion cubic feet

.0652 feet depth on Red Lake (at Elevation 1173.5)

.1740 inches depth on Red Lake Drainage Area

1,000 cubic feet per second for 3 months equals:

7.88 billion cubic feet

.652 feet depth on Red Lake (at Elevation 1173.5)

1.740 inches depth on Red Lake Drainage Area

100 cubic feet per second for 6 months equals:

1.576 billion cubic feet

.1304 feet depth on Red Lake (at Elevation 1173.5)

.3480 inches depth on Red Lake Drainage Area

1,000 cubic feet per second for 6 months equals:

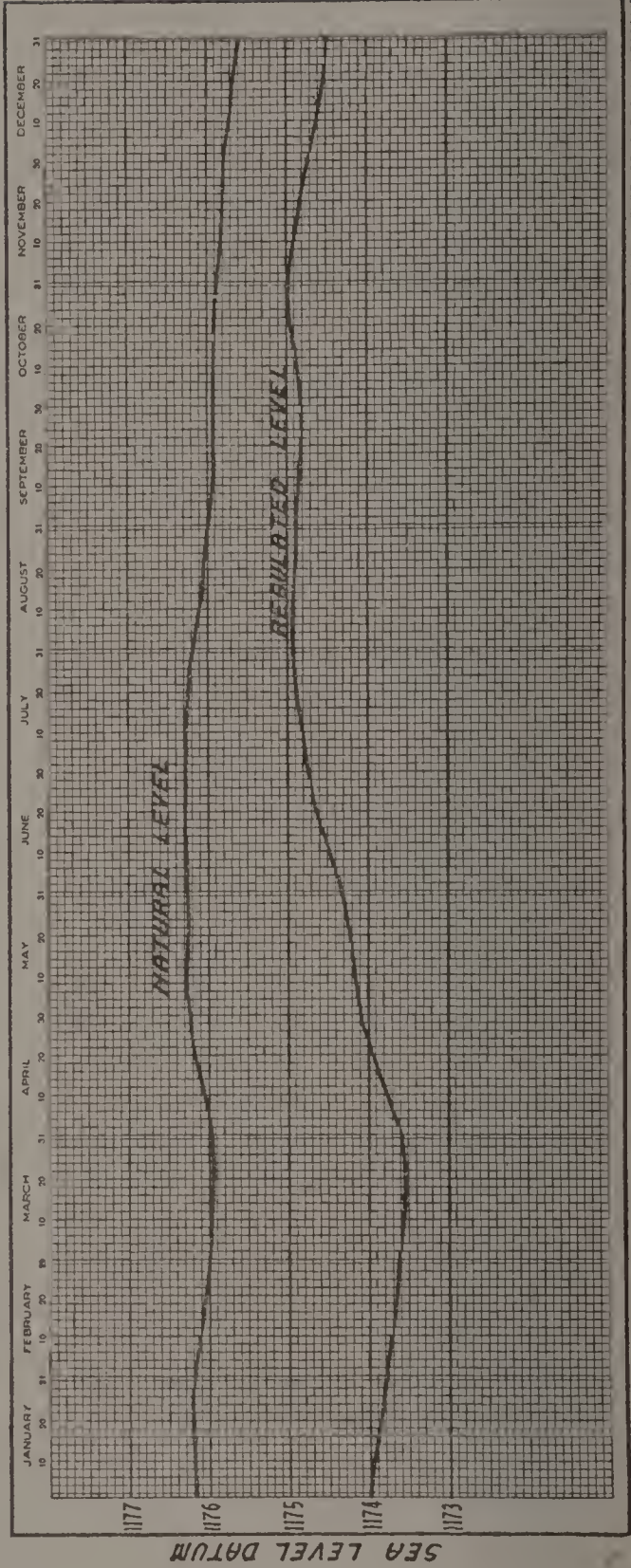
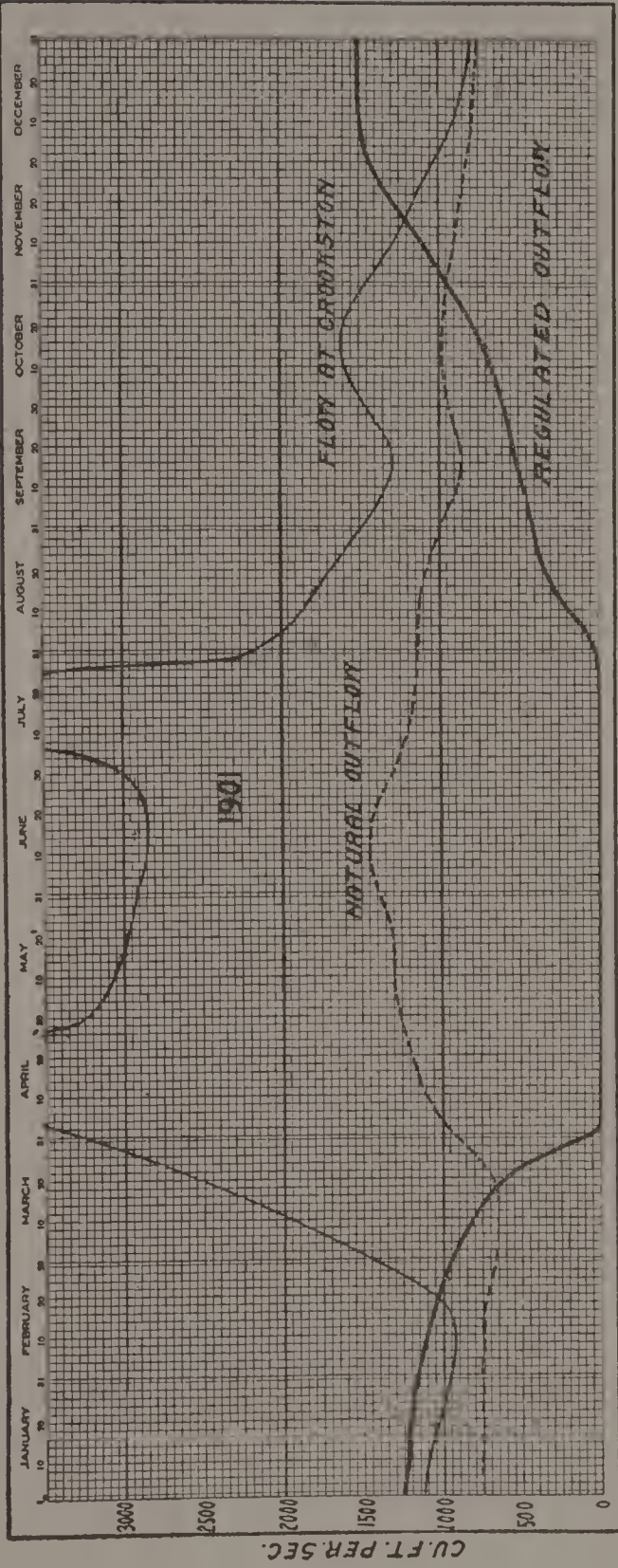
15.76 billion cubic feet

1.304 feet depth on Red Lake (at Elevation 1173.5)

3.480 inches depth on Red Lake Drainage Area.

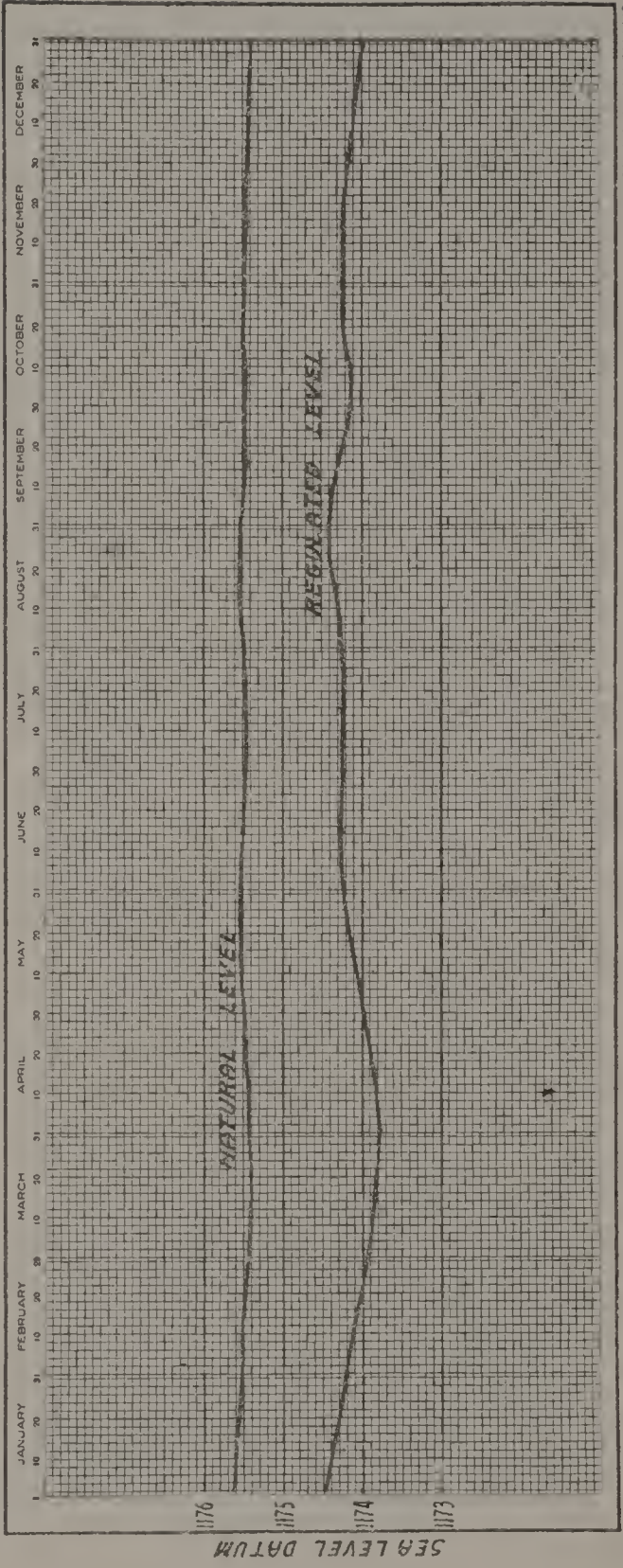
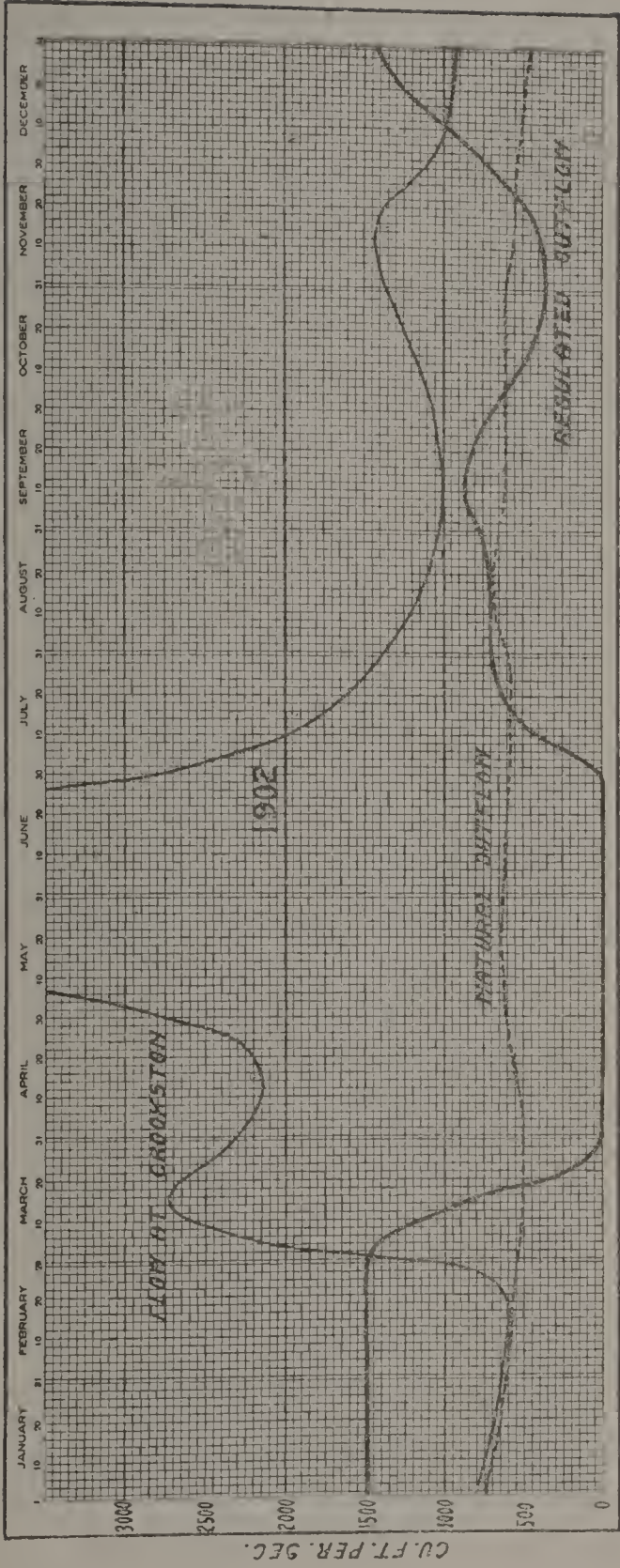
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Note—1 month taken as 30 days; 3 months as one-fourth year.



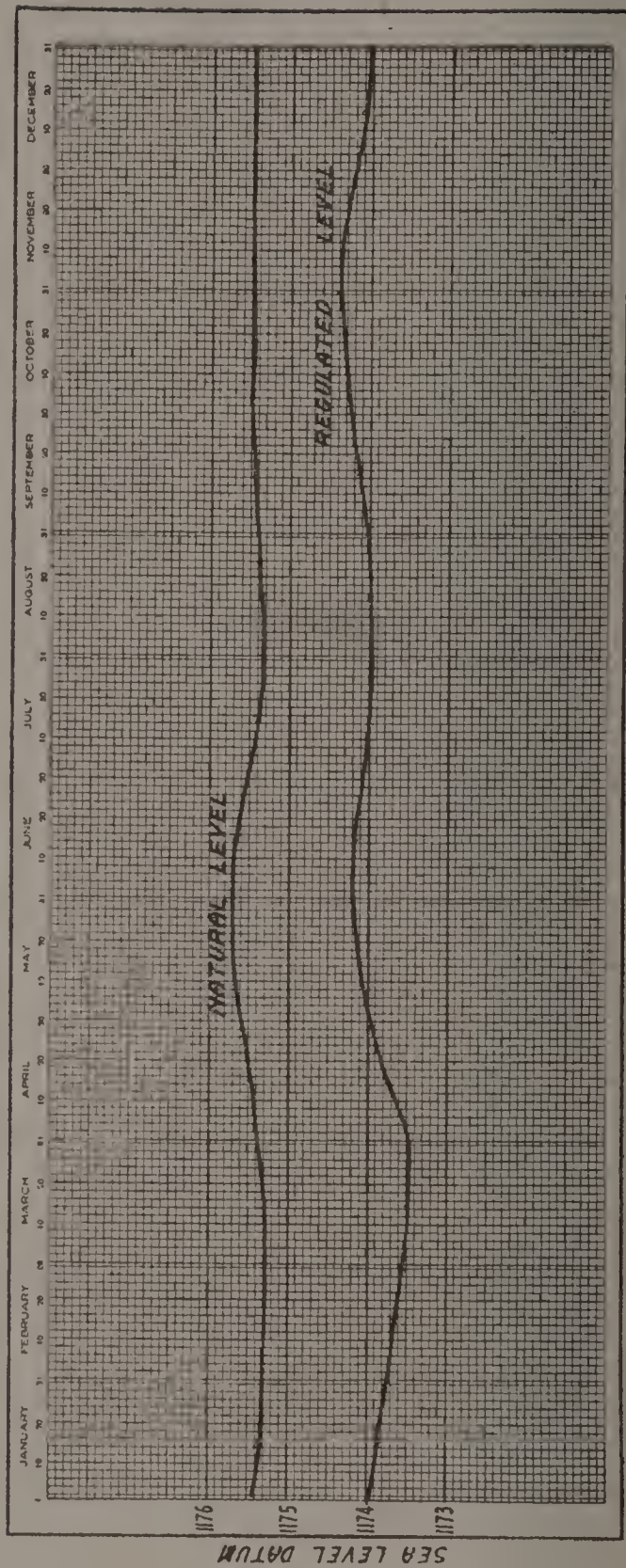
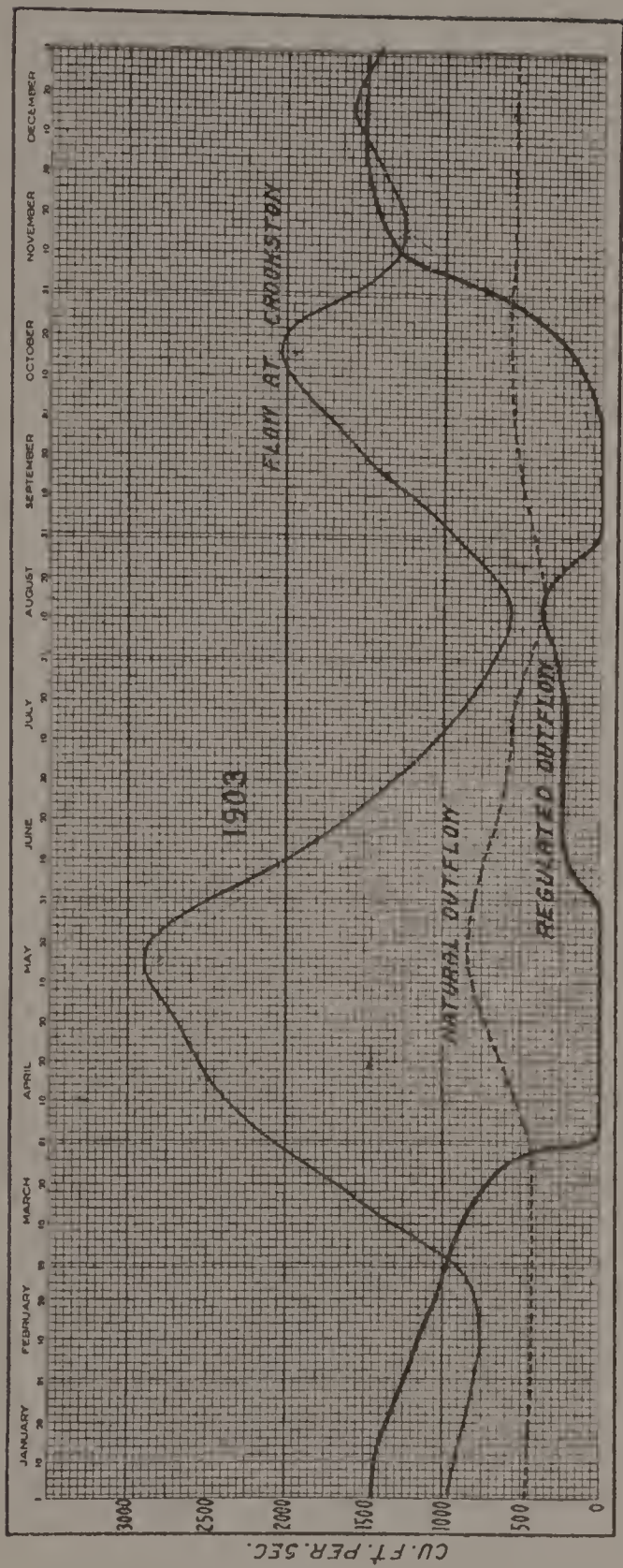
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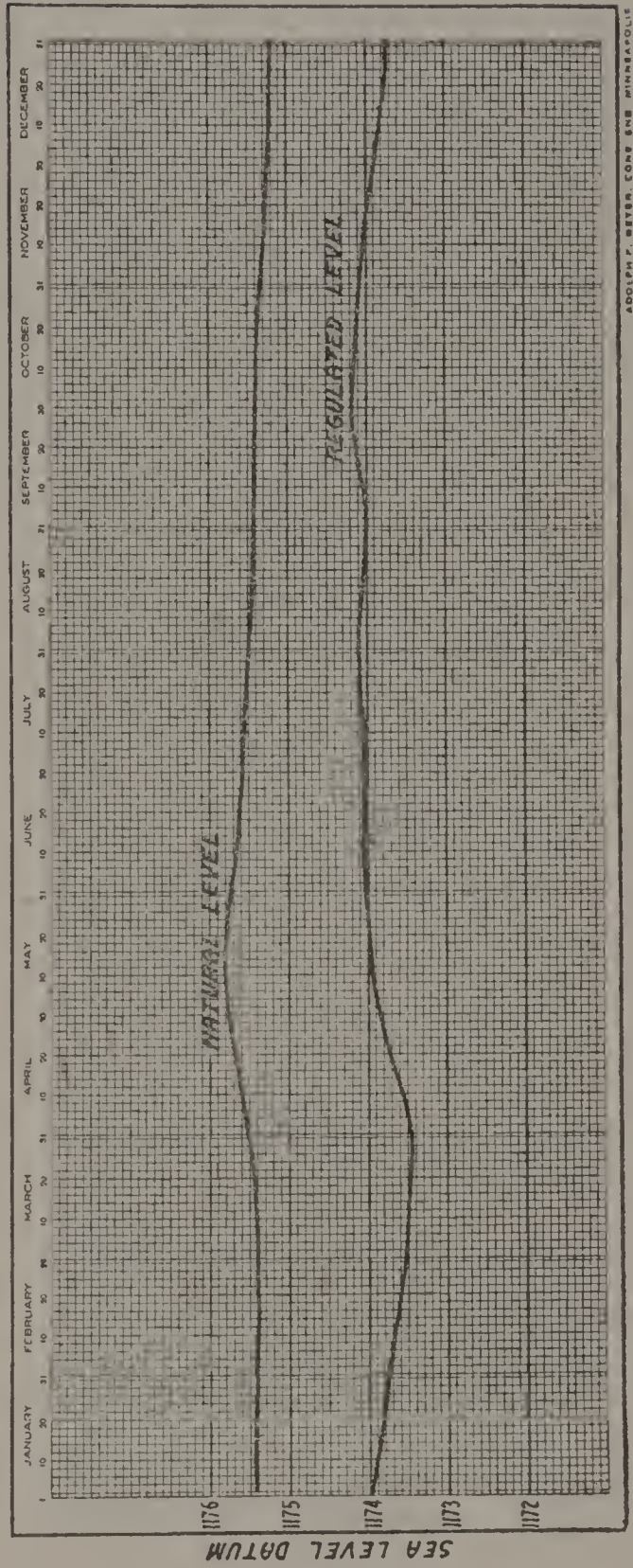
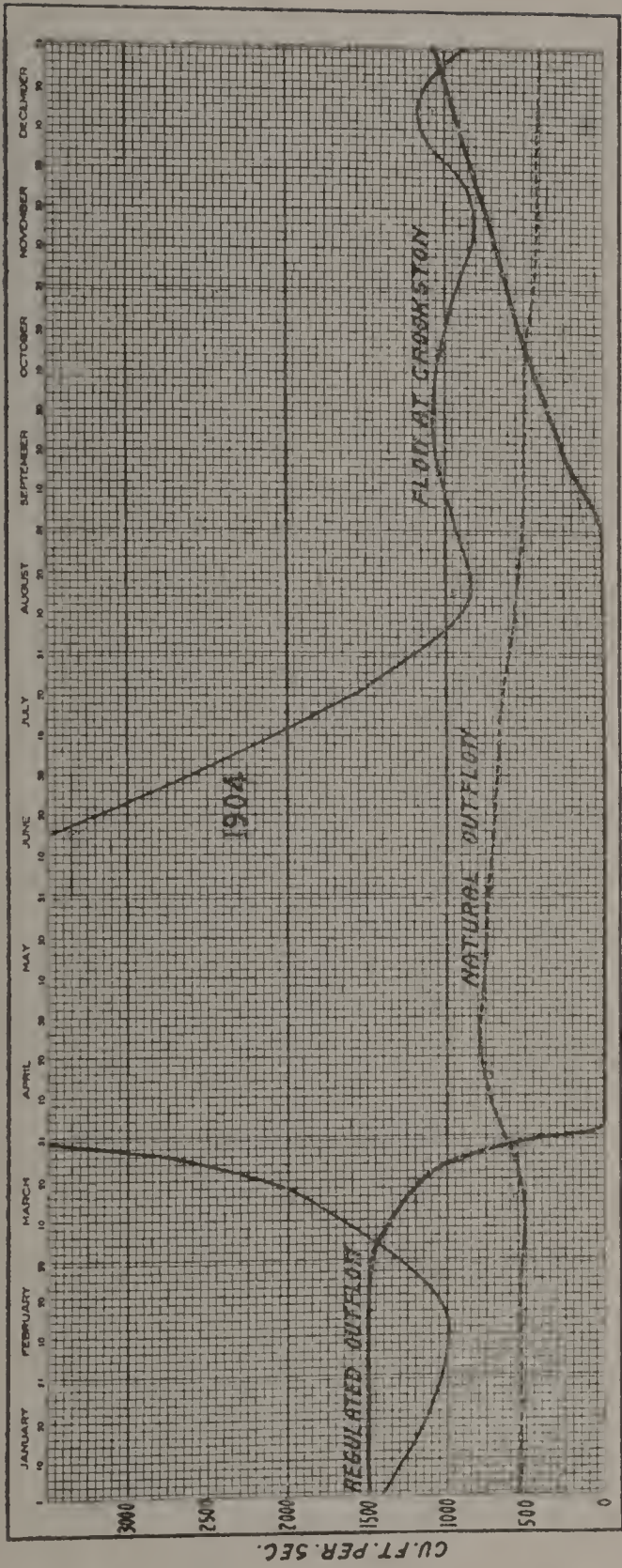
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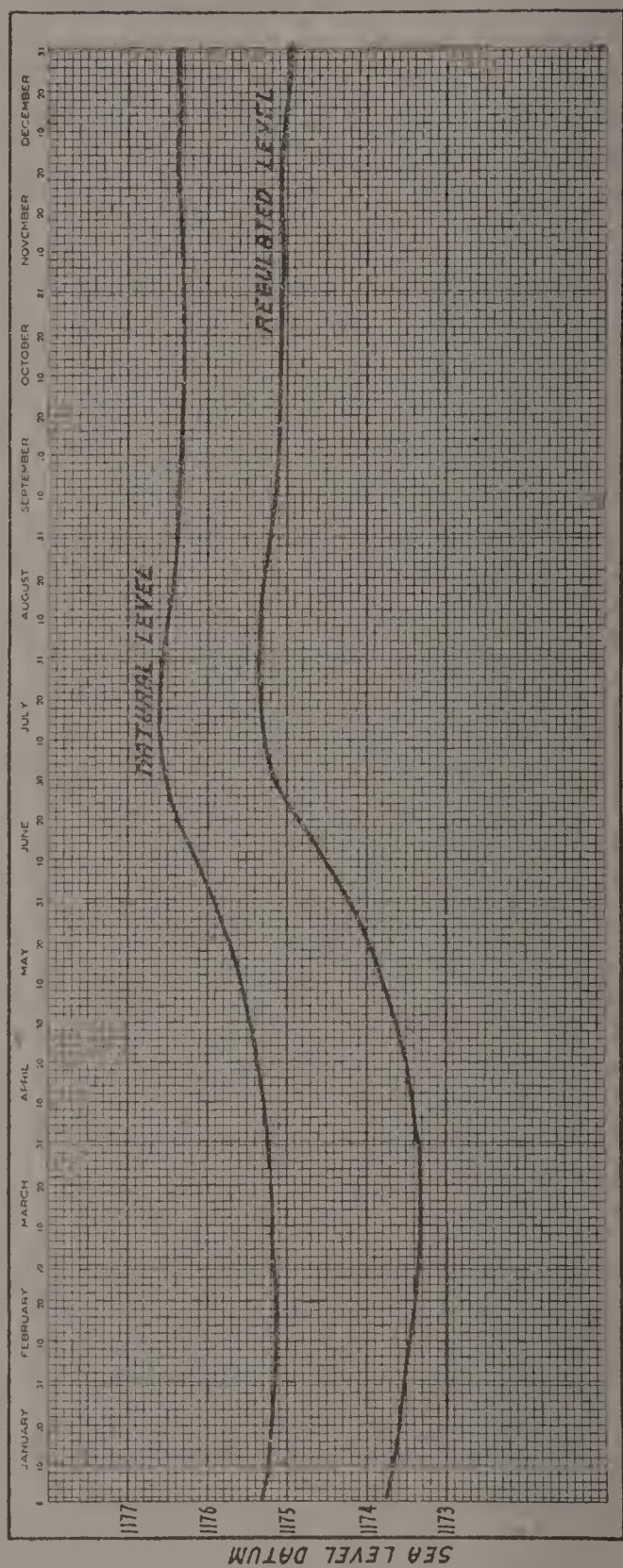
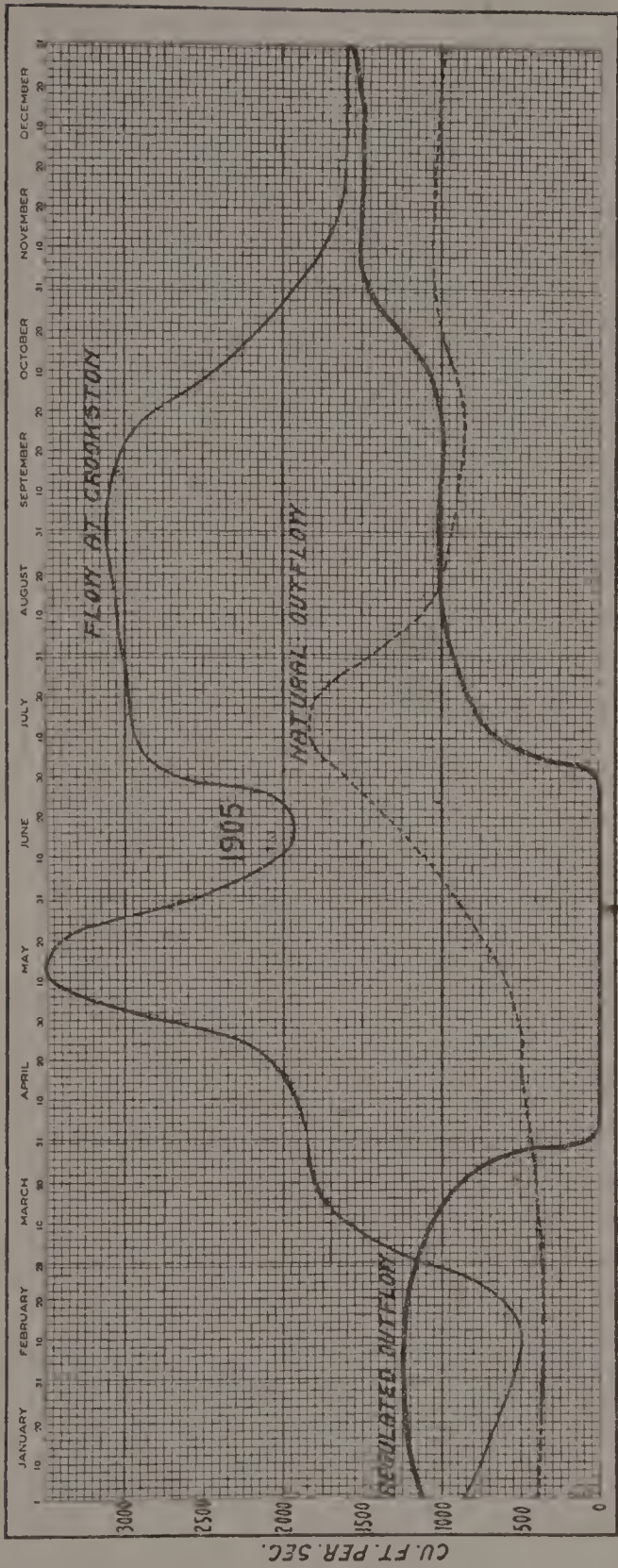
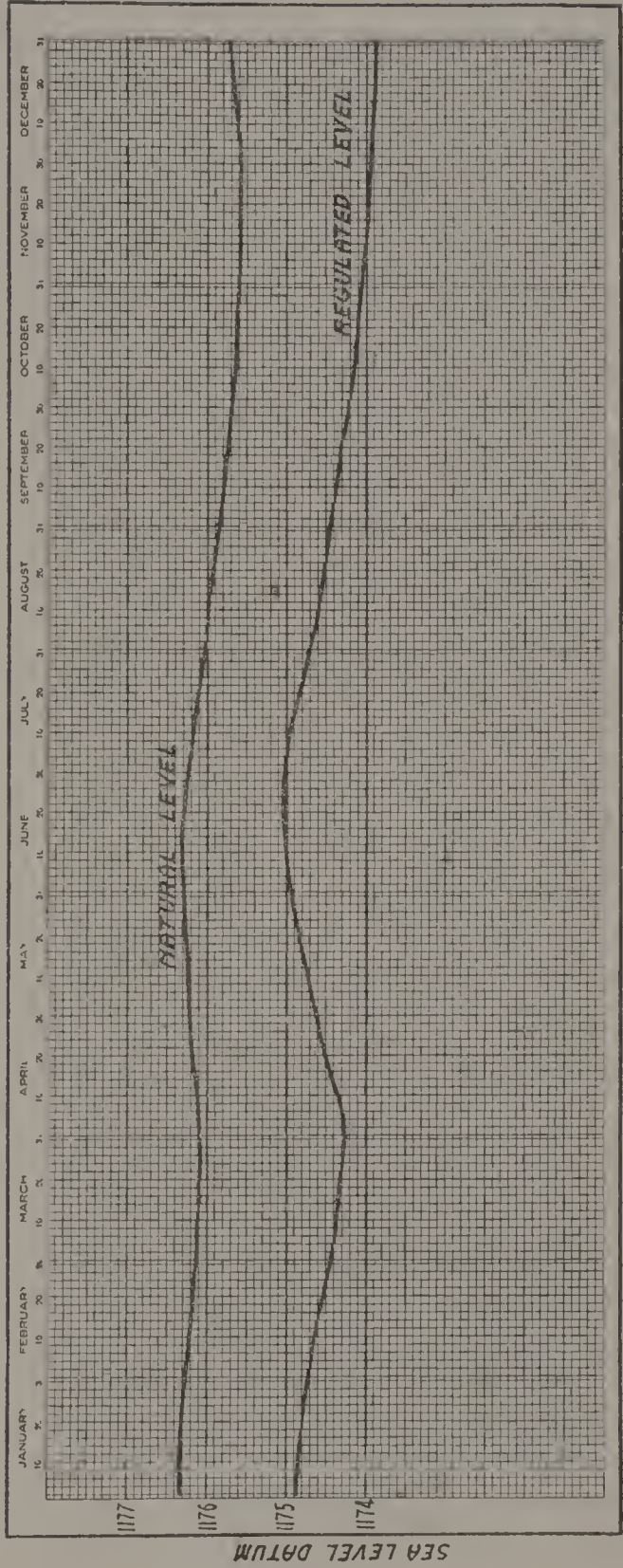
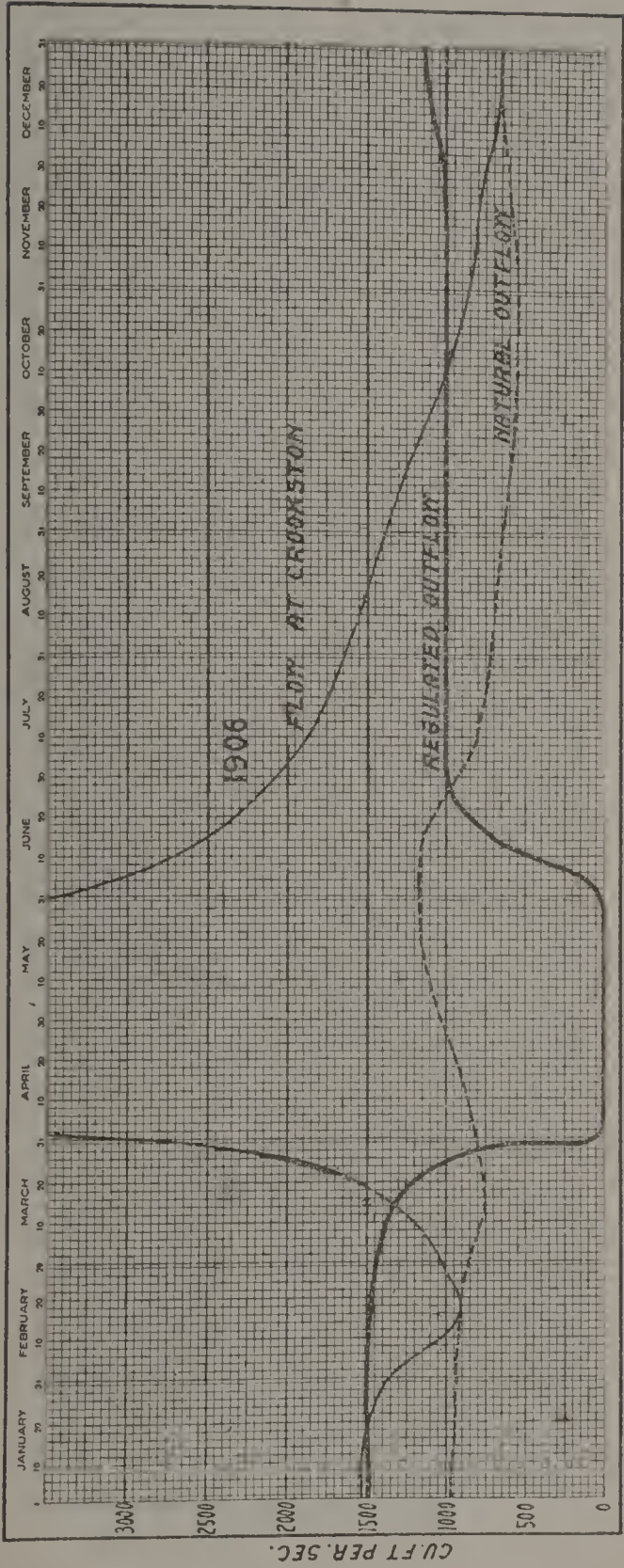


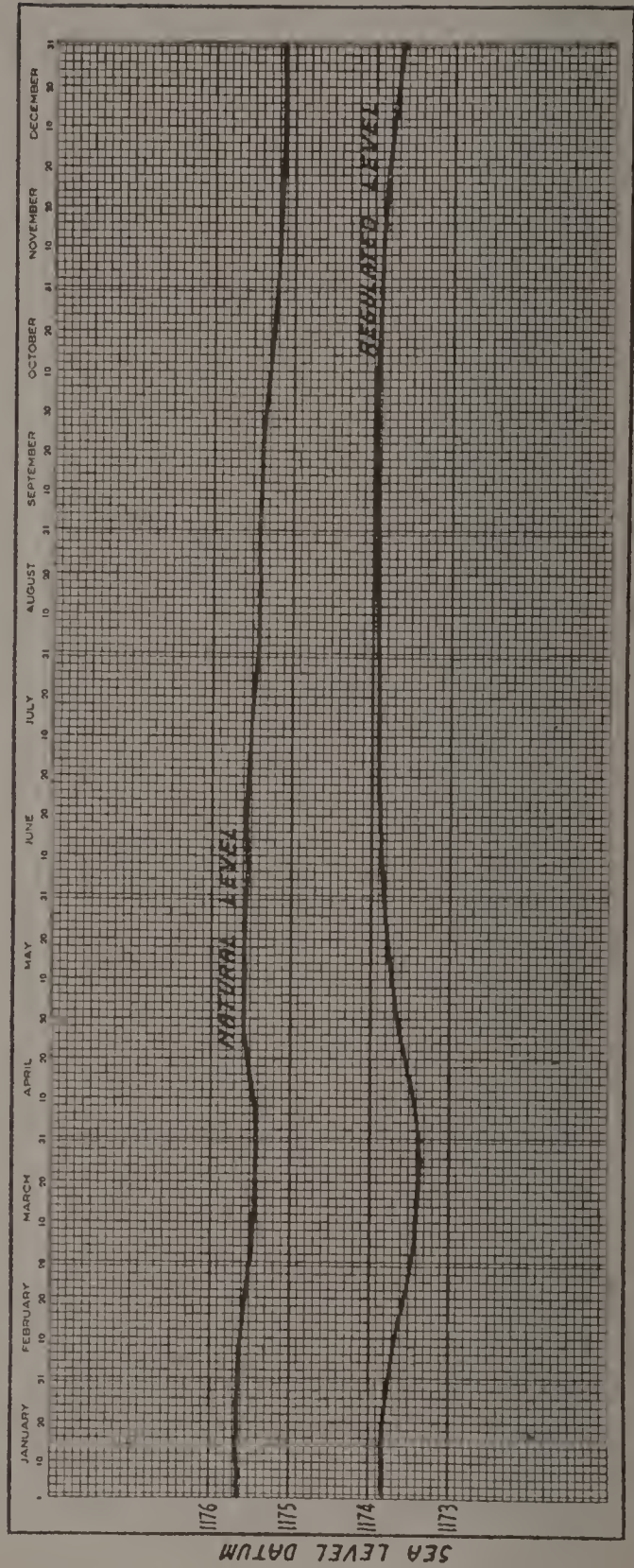
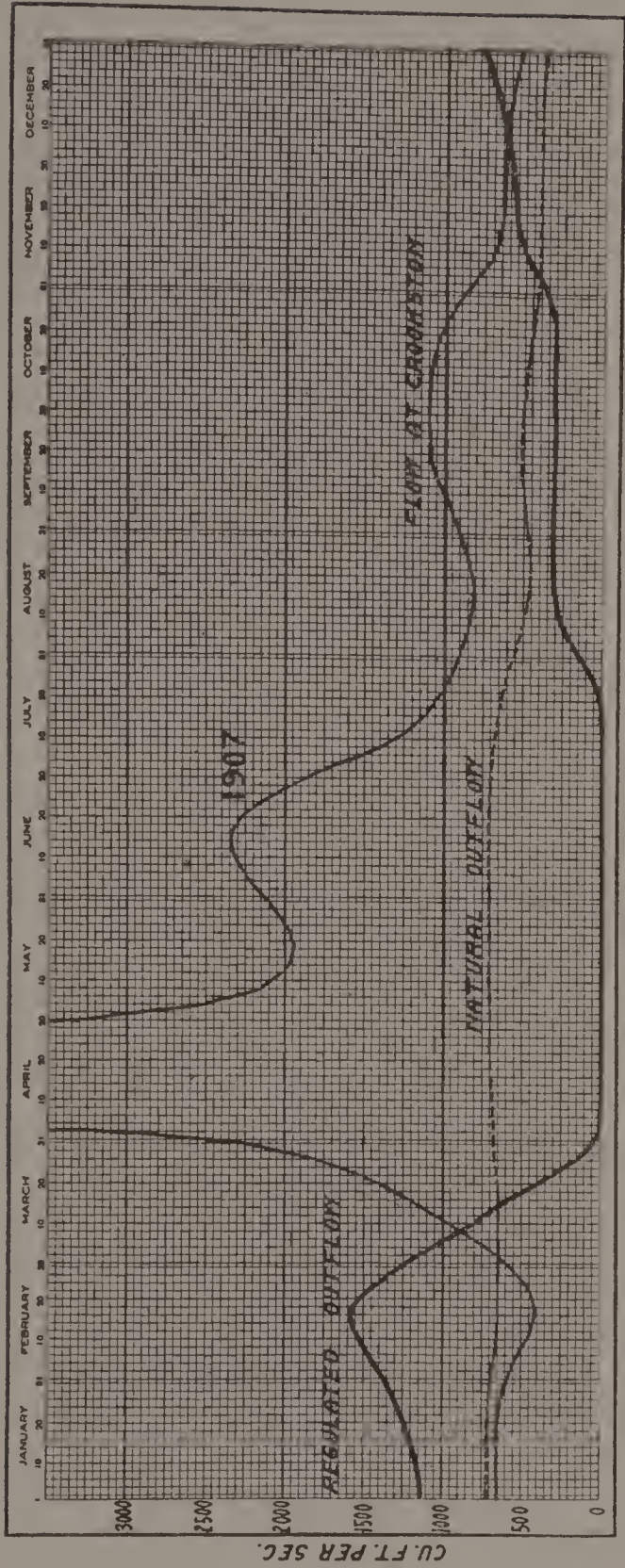
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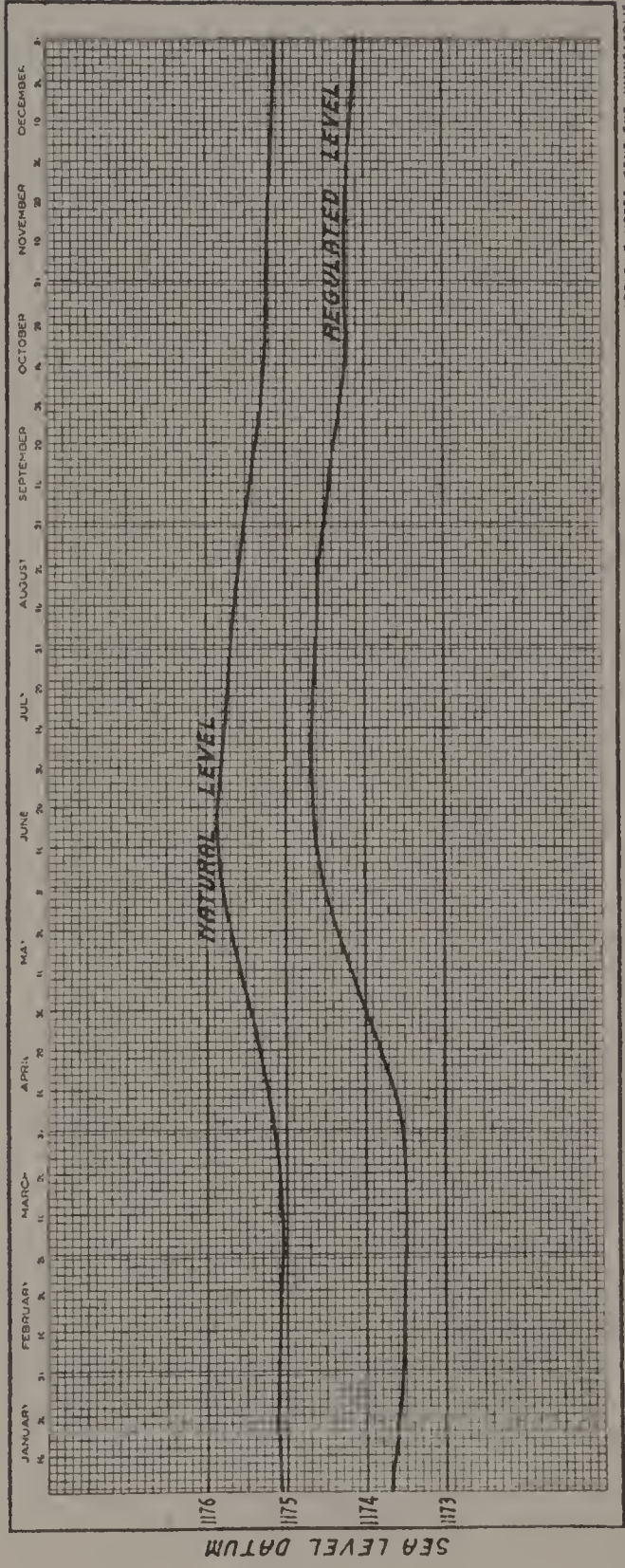
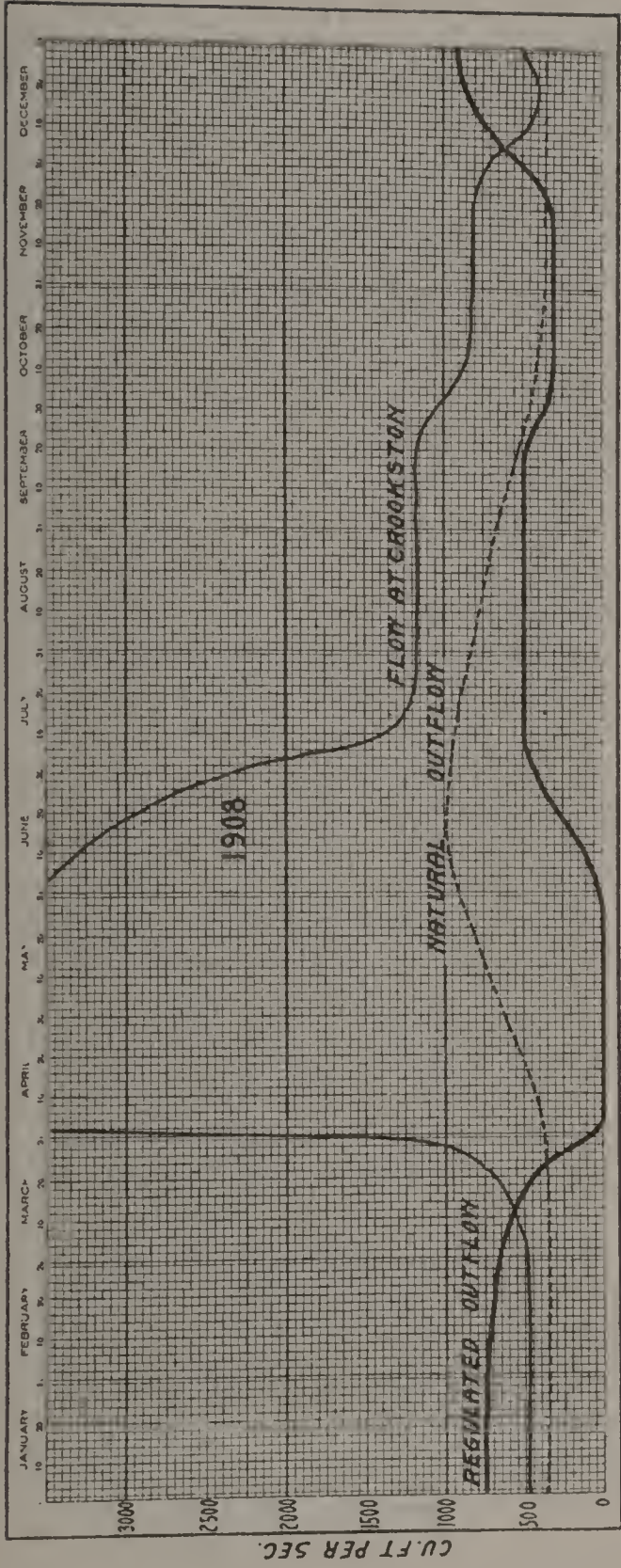
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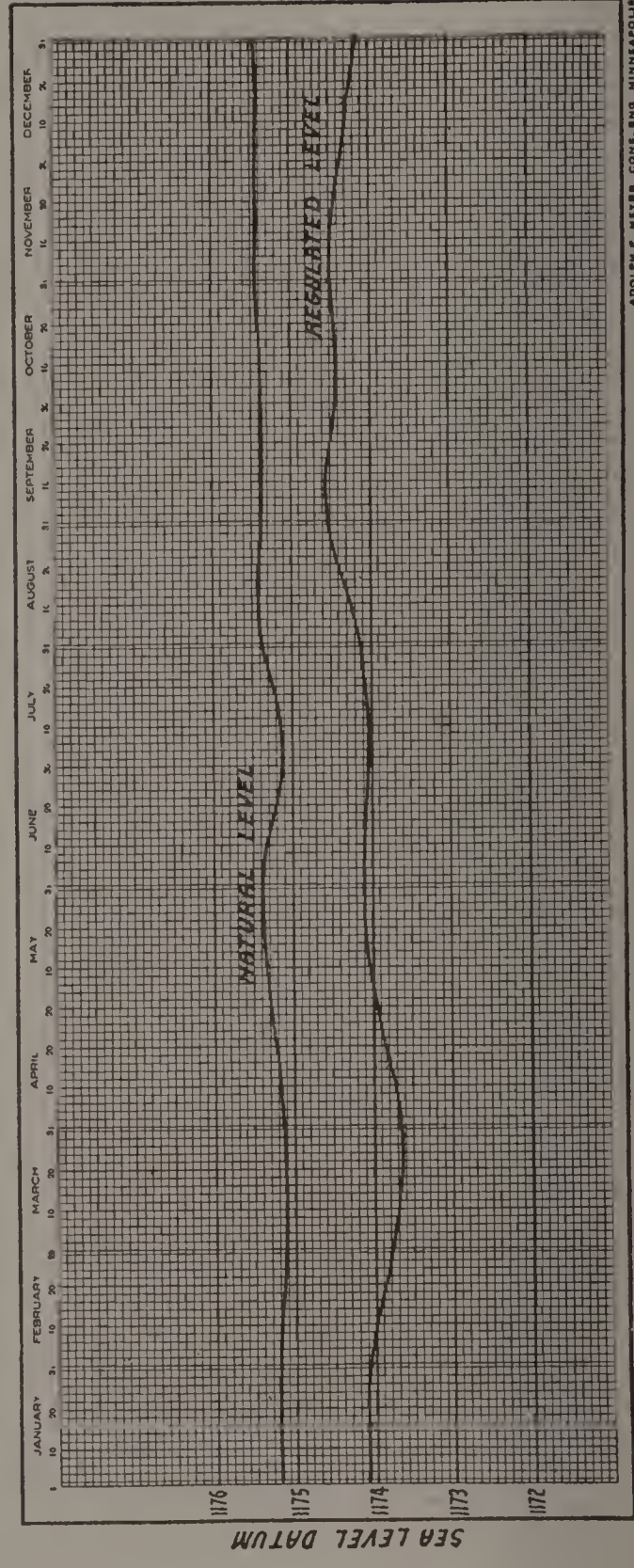
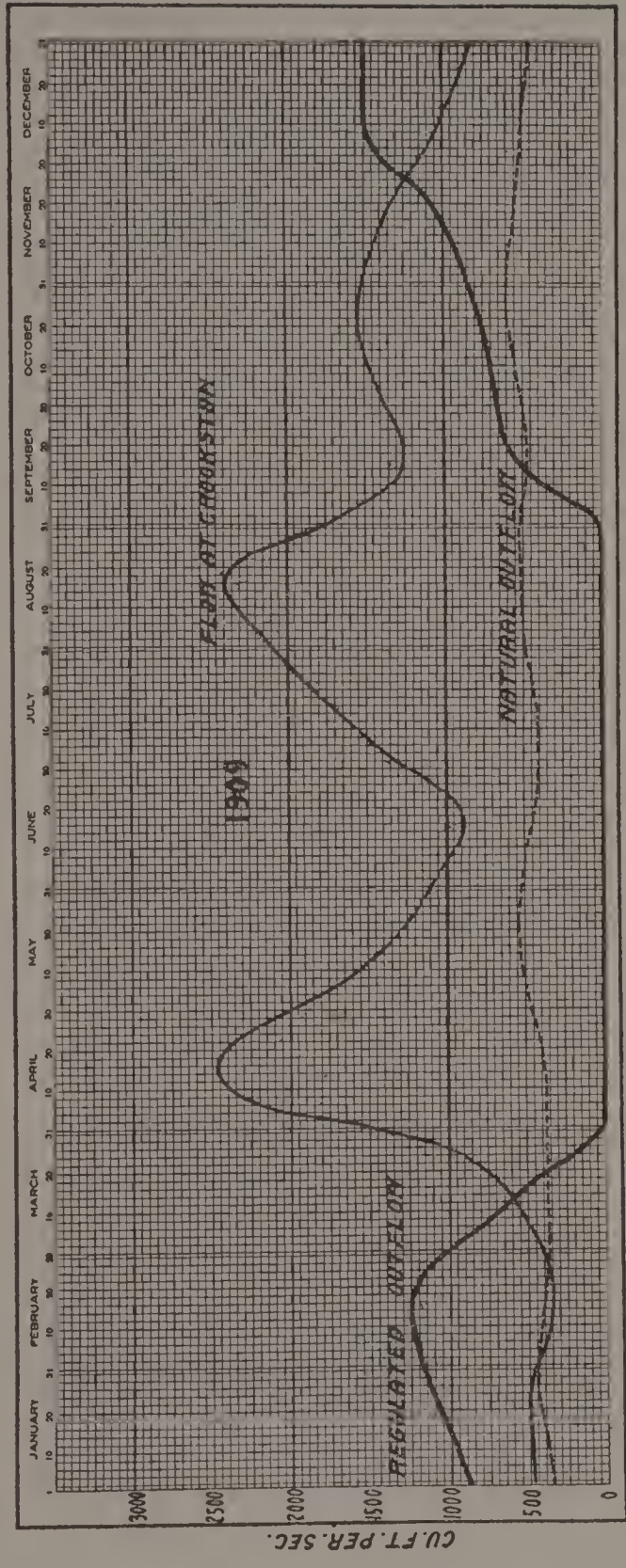
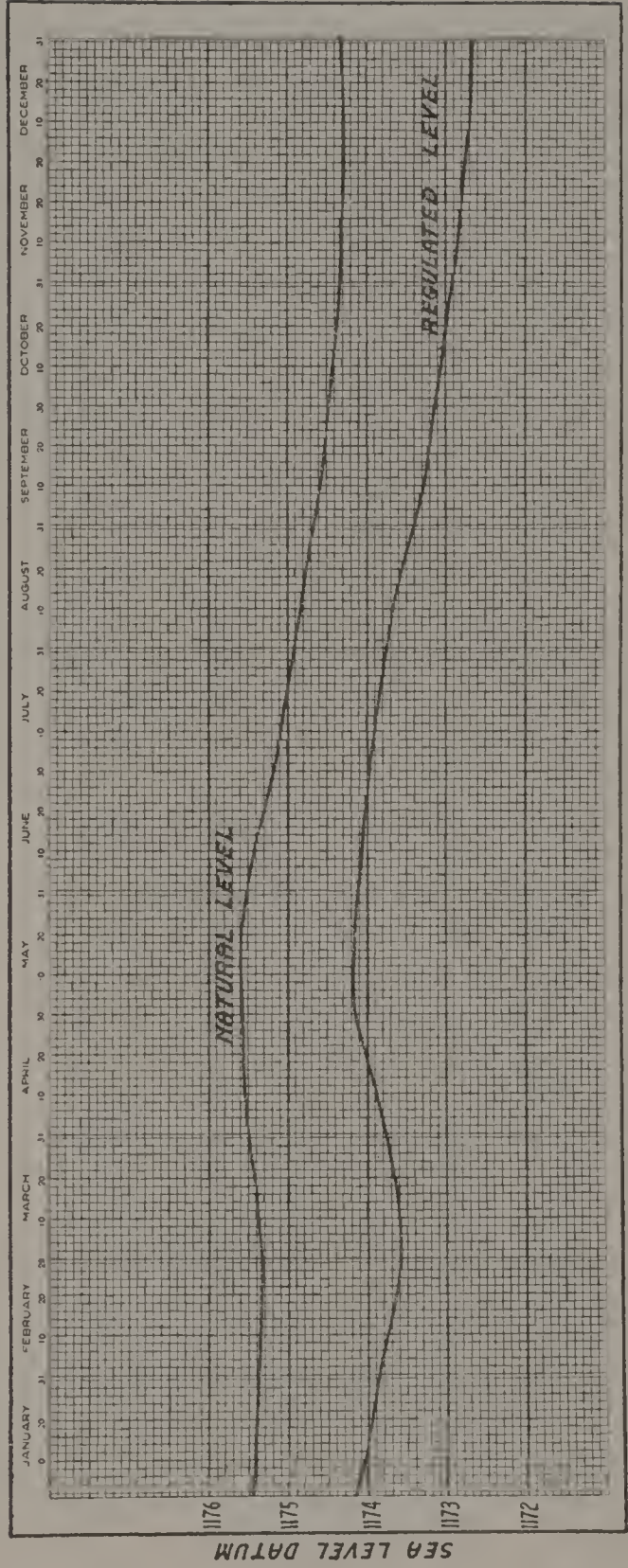
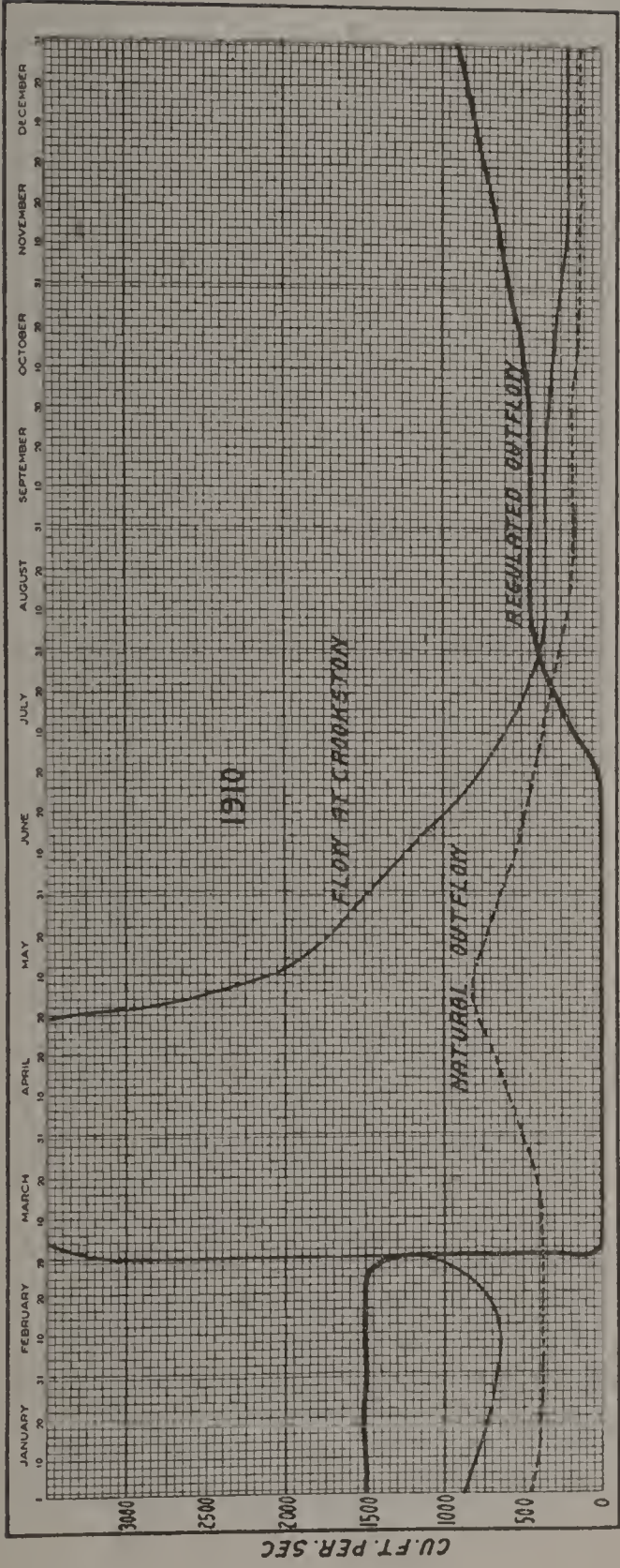


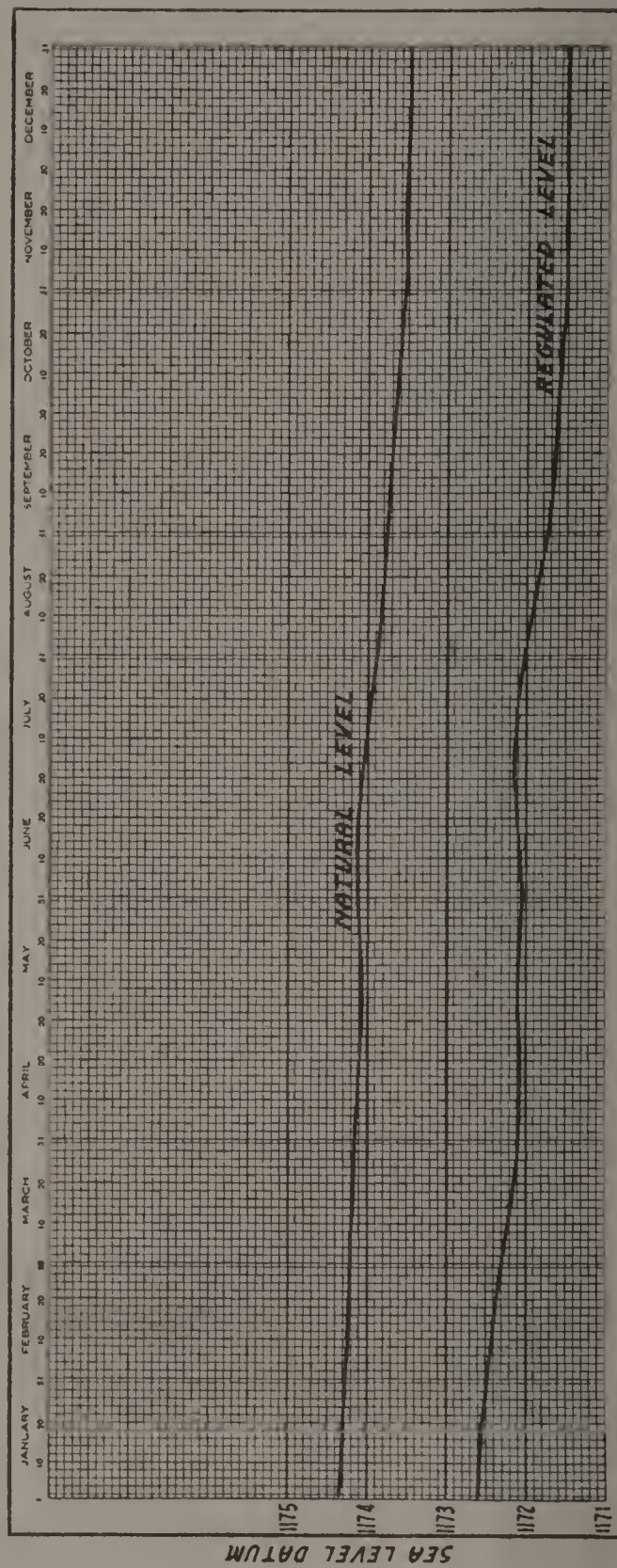
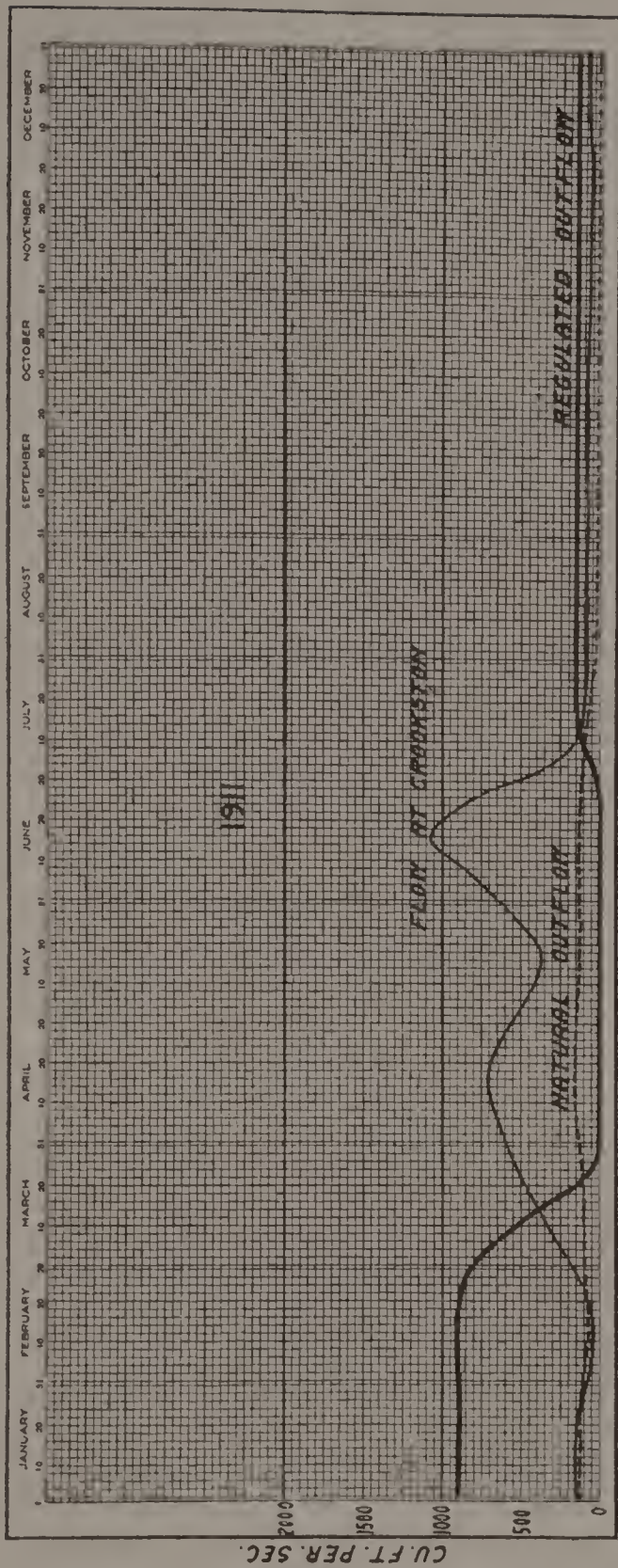
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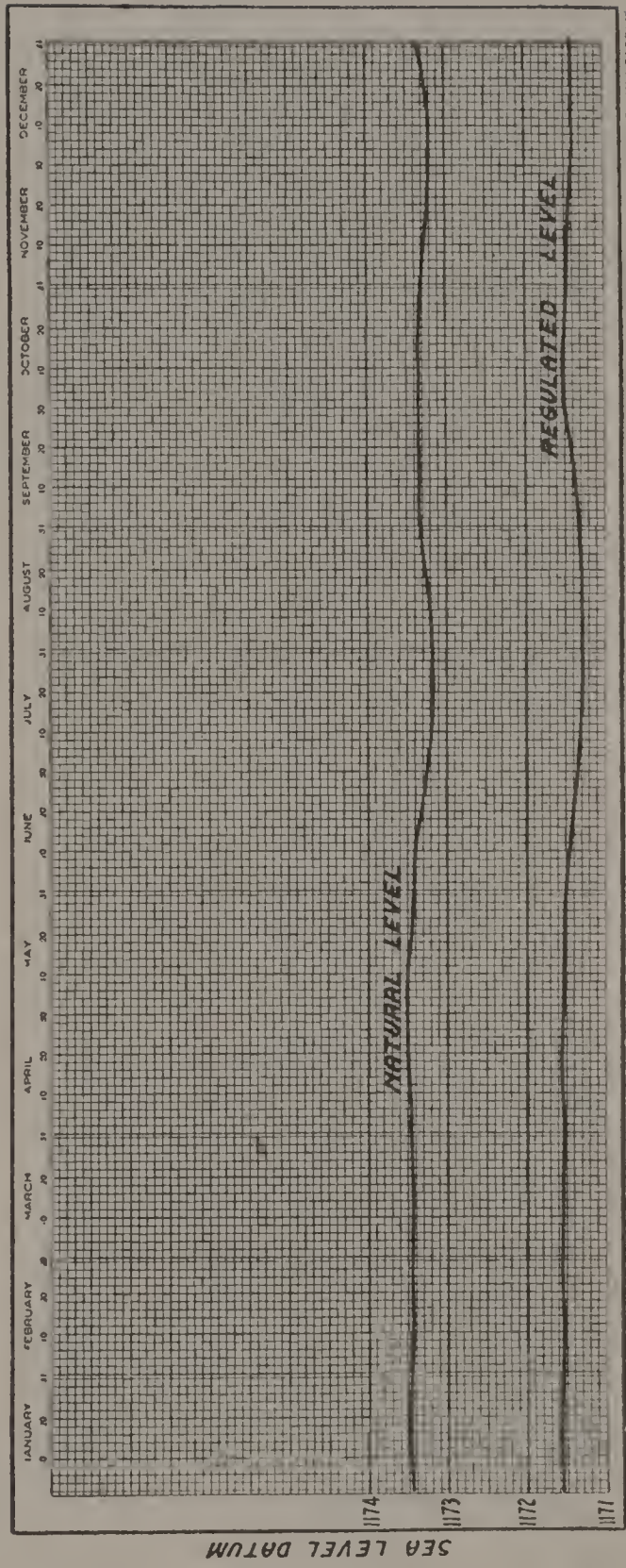
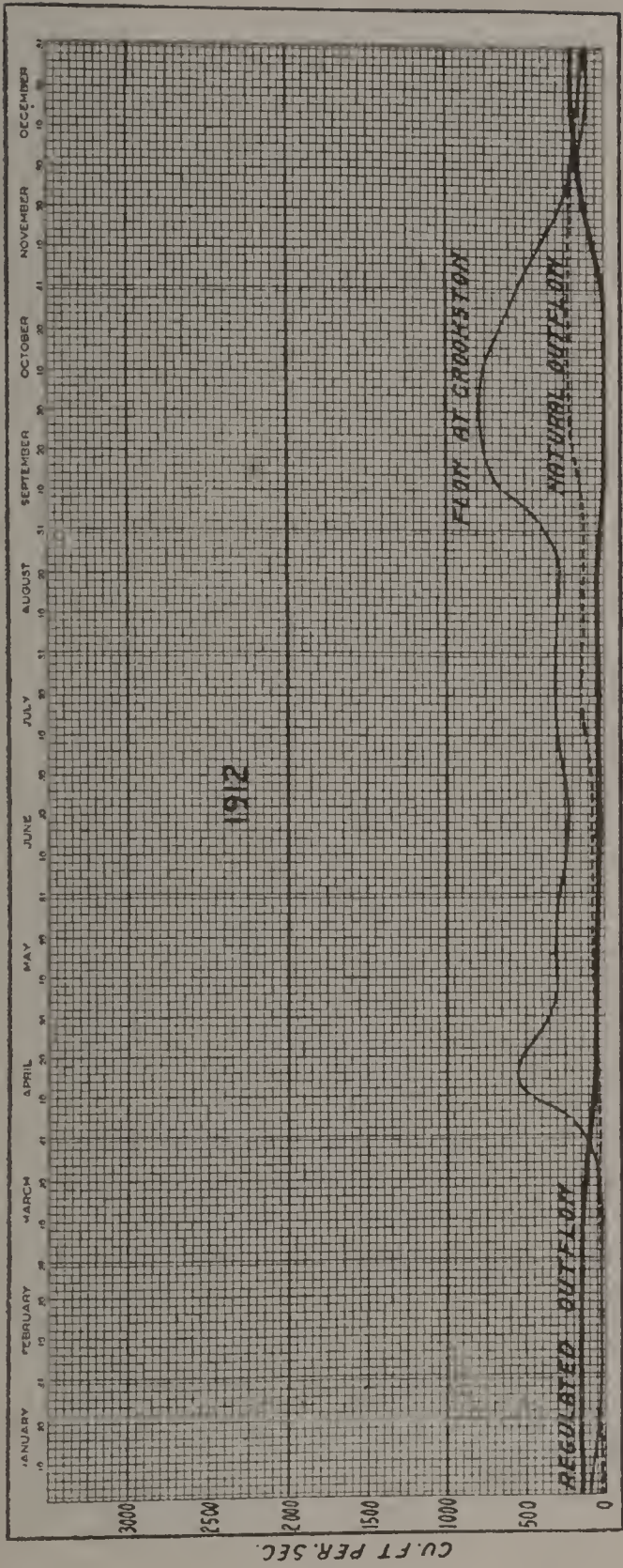
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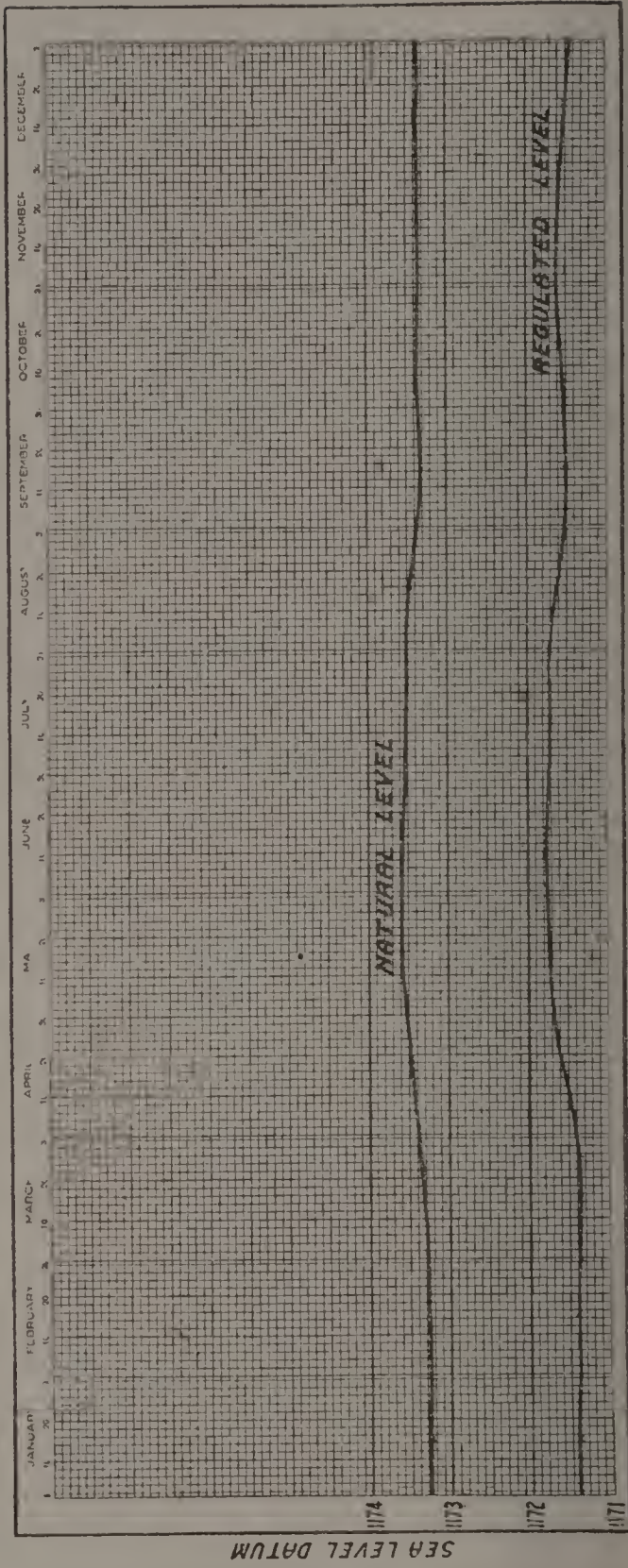
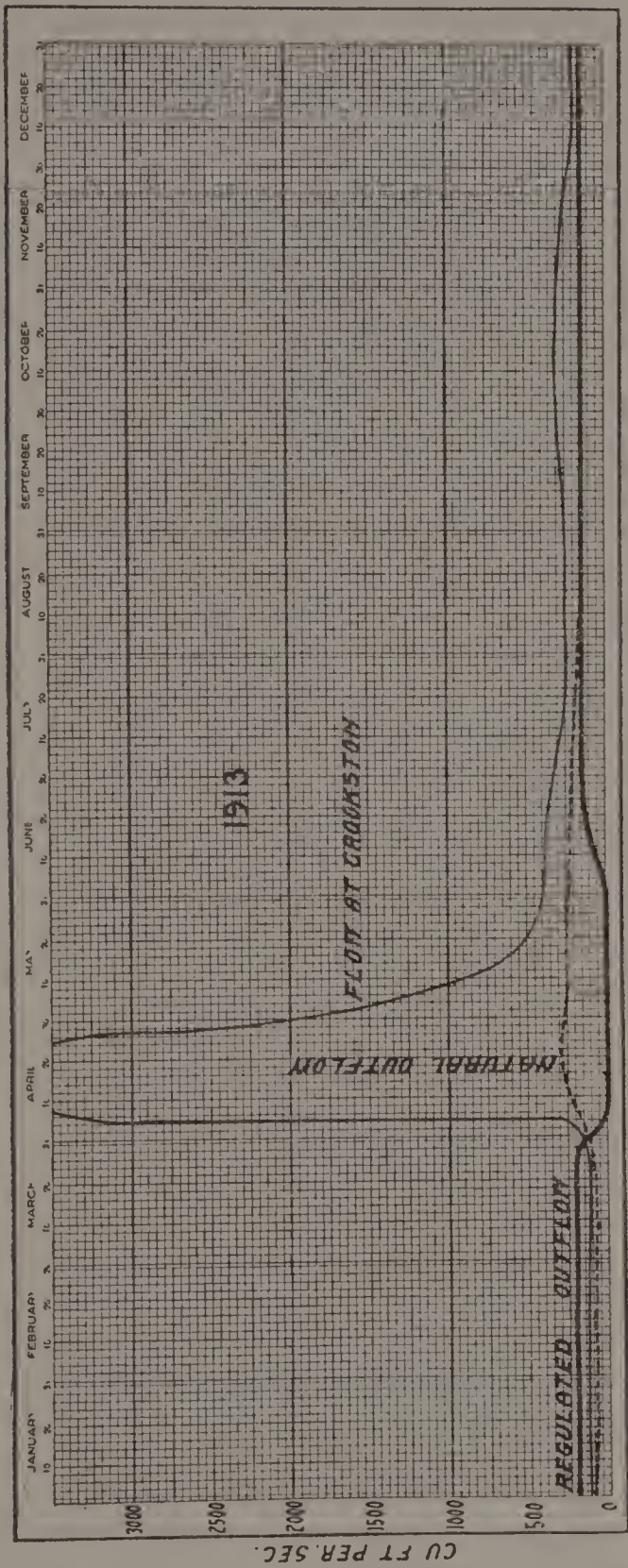
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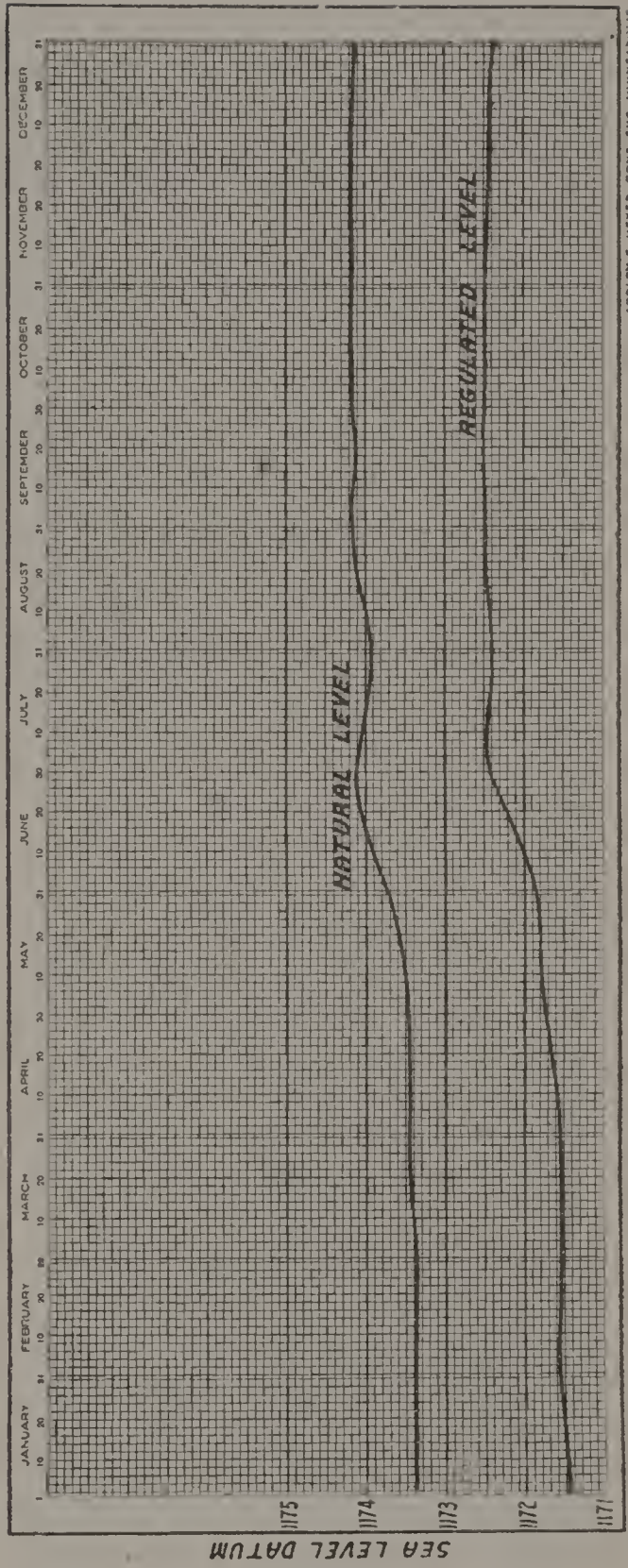
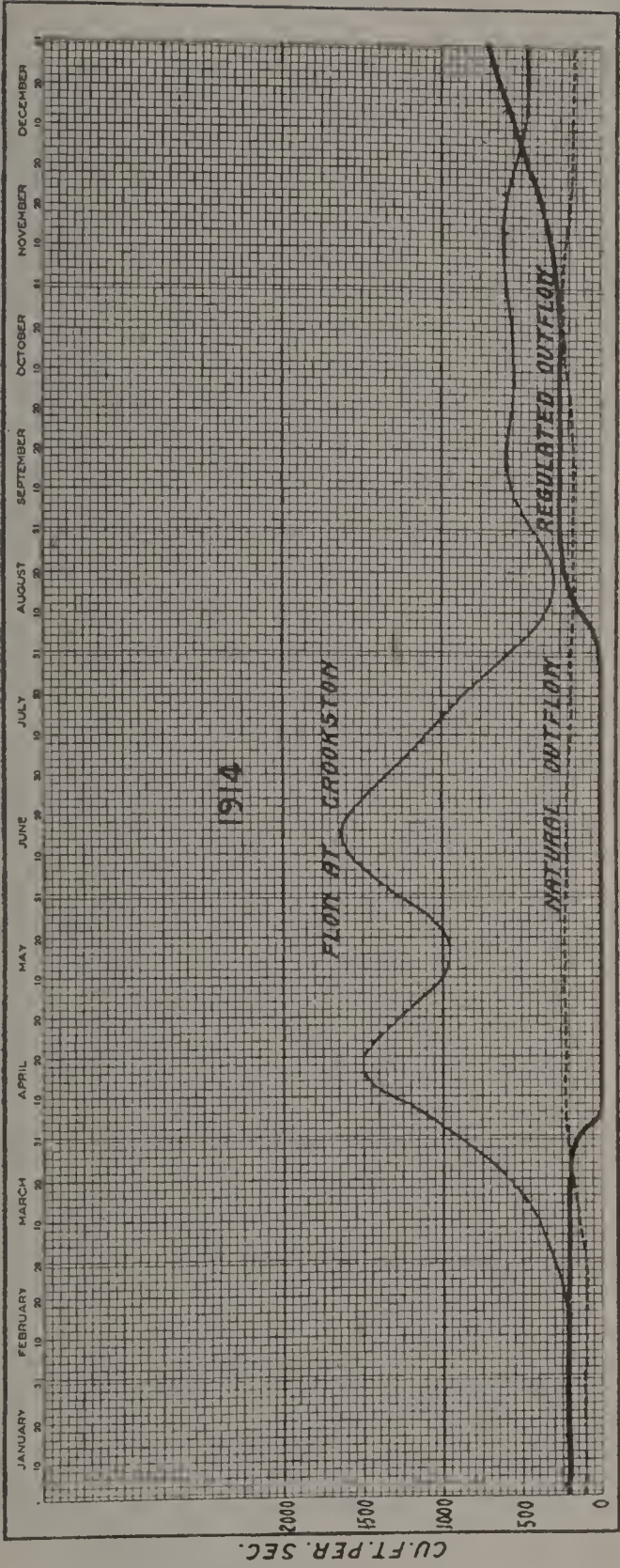
ADOLPH MEYER CONSULTING ENGINEERS MINNEAPOLIS

CHART NO. 12



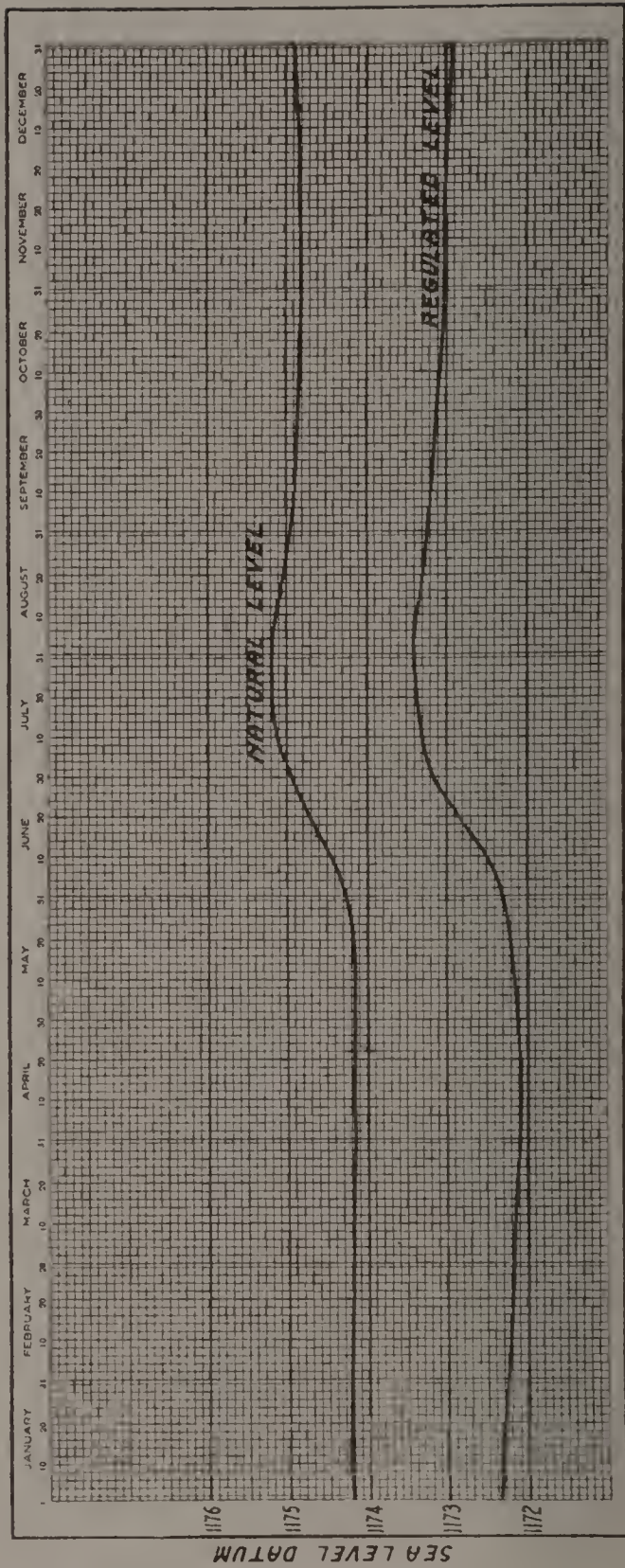
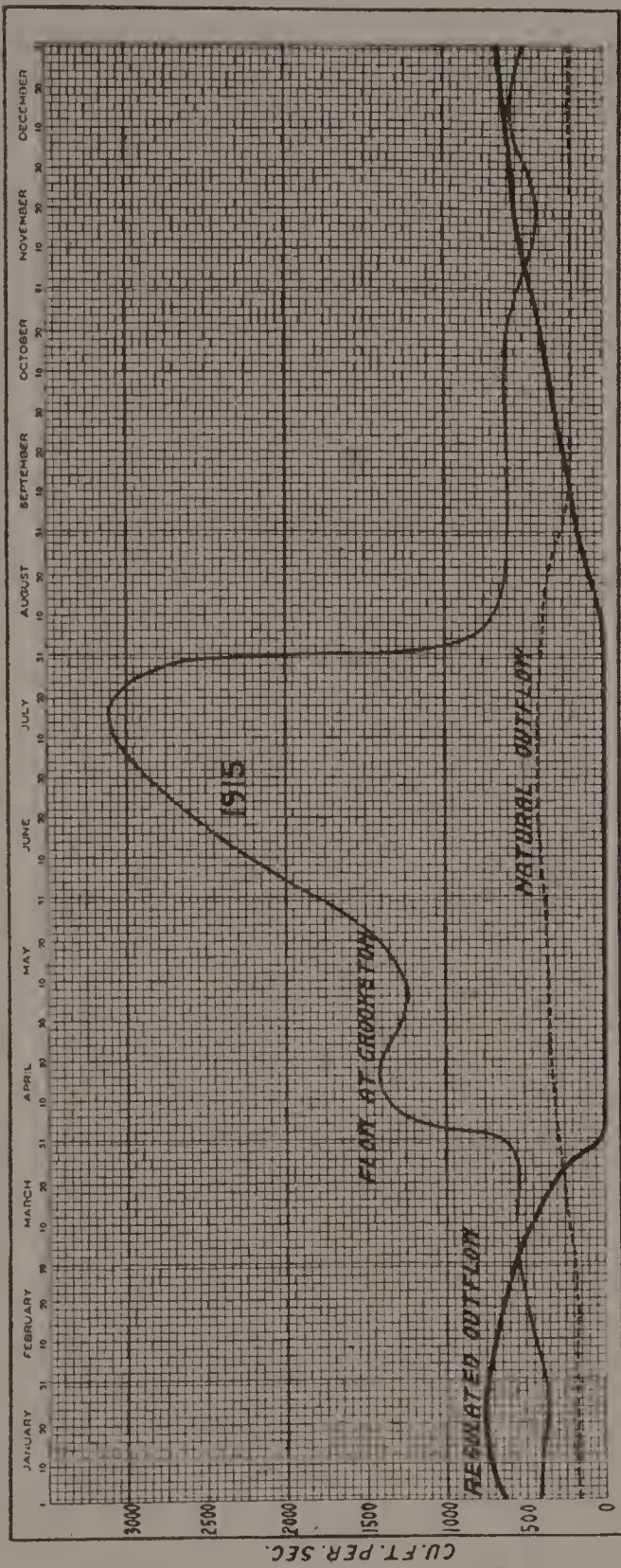
ADOLPH F. MEYER CONSULTING ENGINEERS

CHART NO. 13



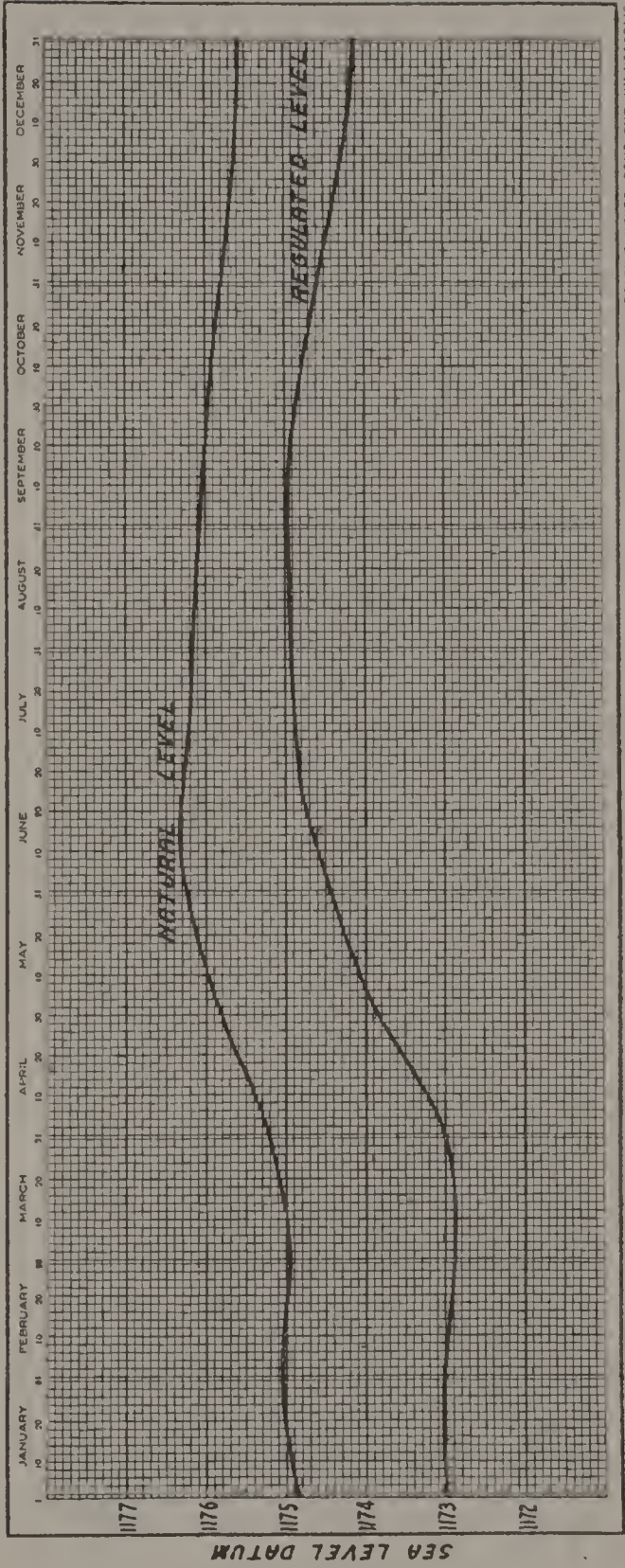
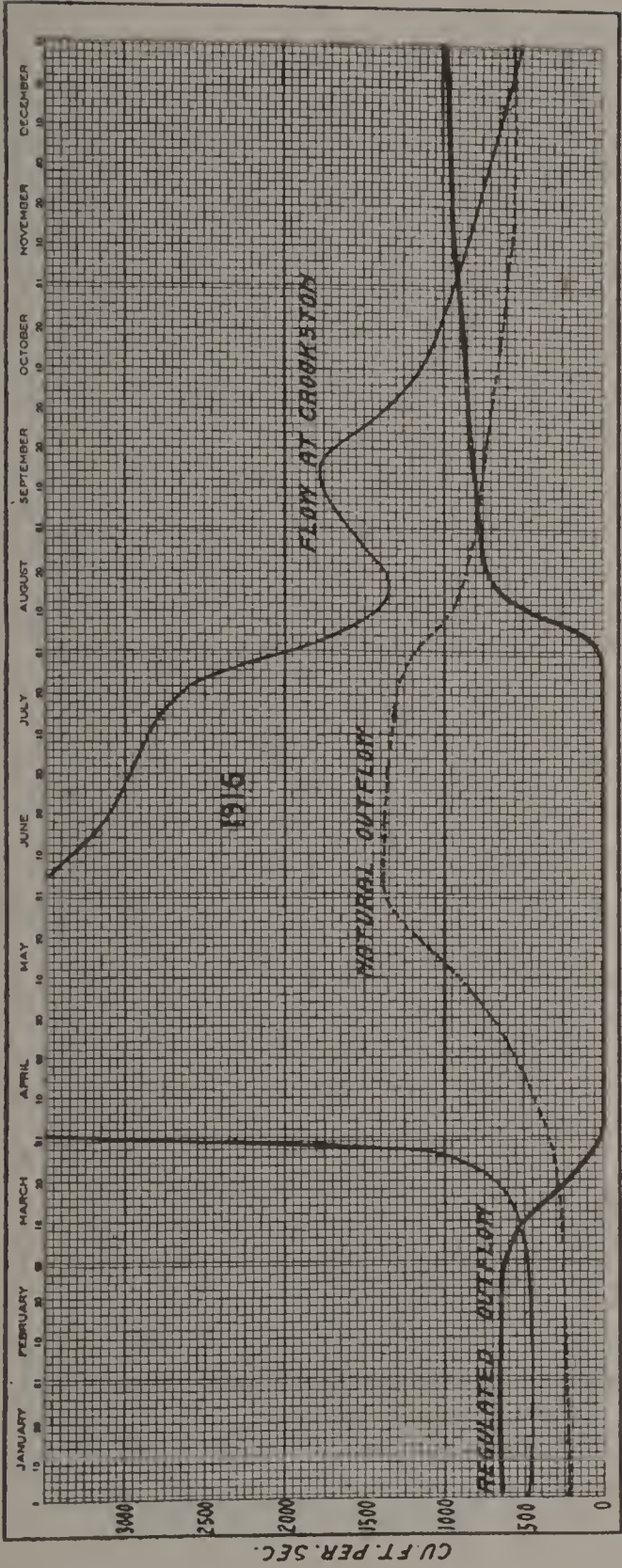
ADOLPH P. MEYER, CONSULTING ENGINEER, MINNEAPOLIS

CHART NO. 11



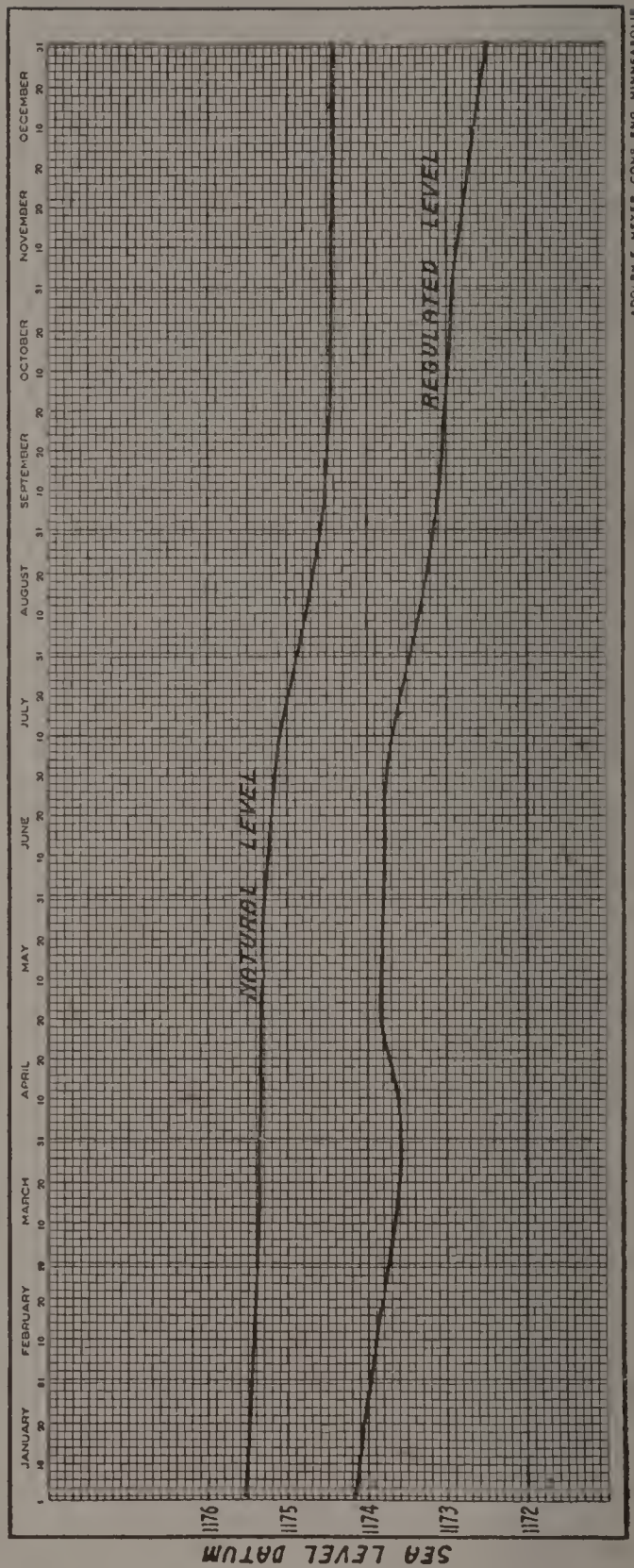
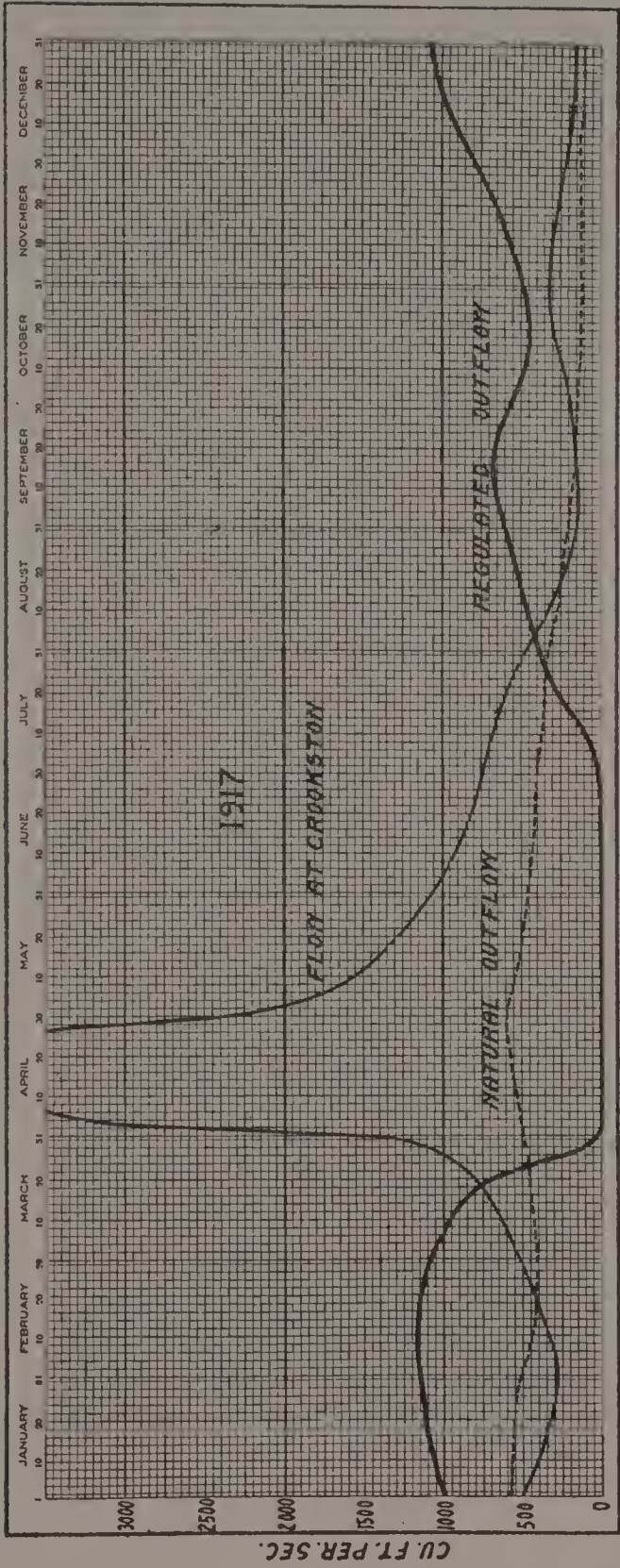
ADOLPH P. MEYER, CONS. ENG. MINNEAPOLIS

CHART NO. 15



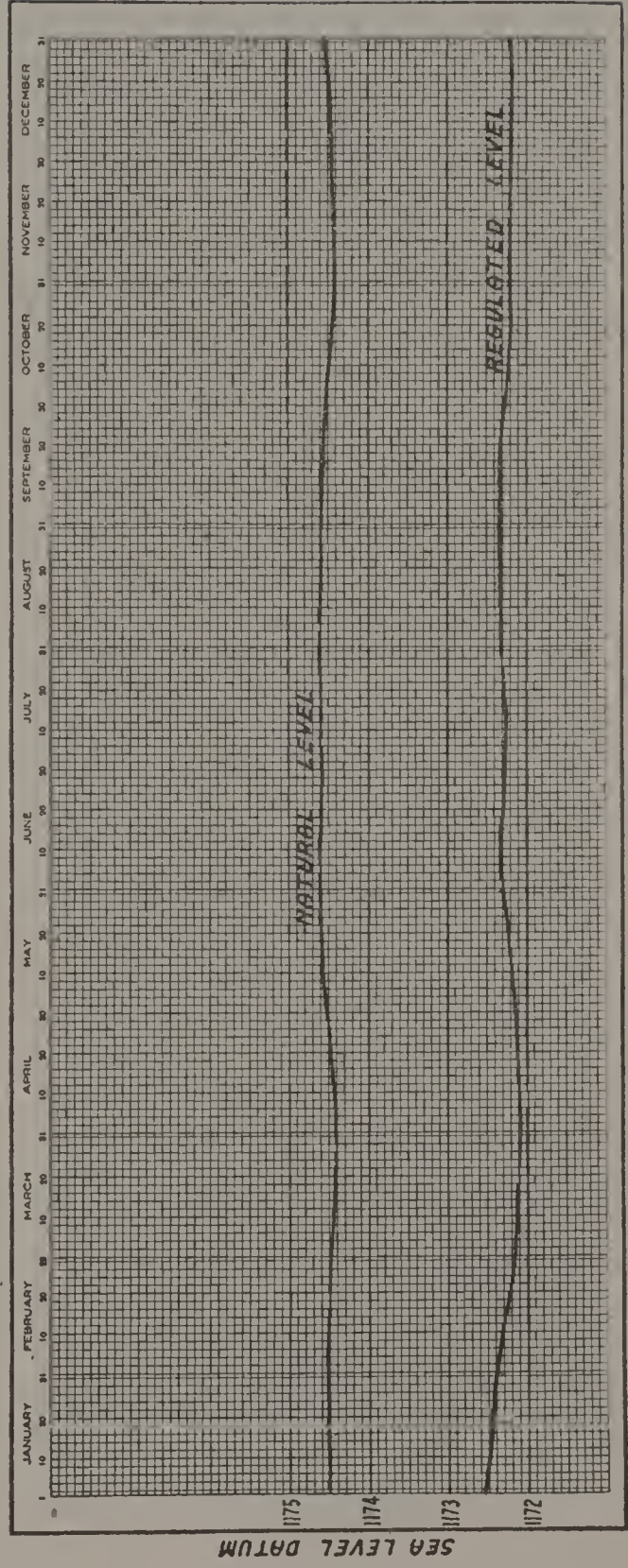
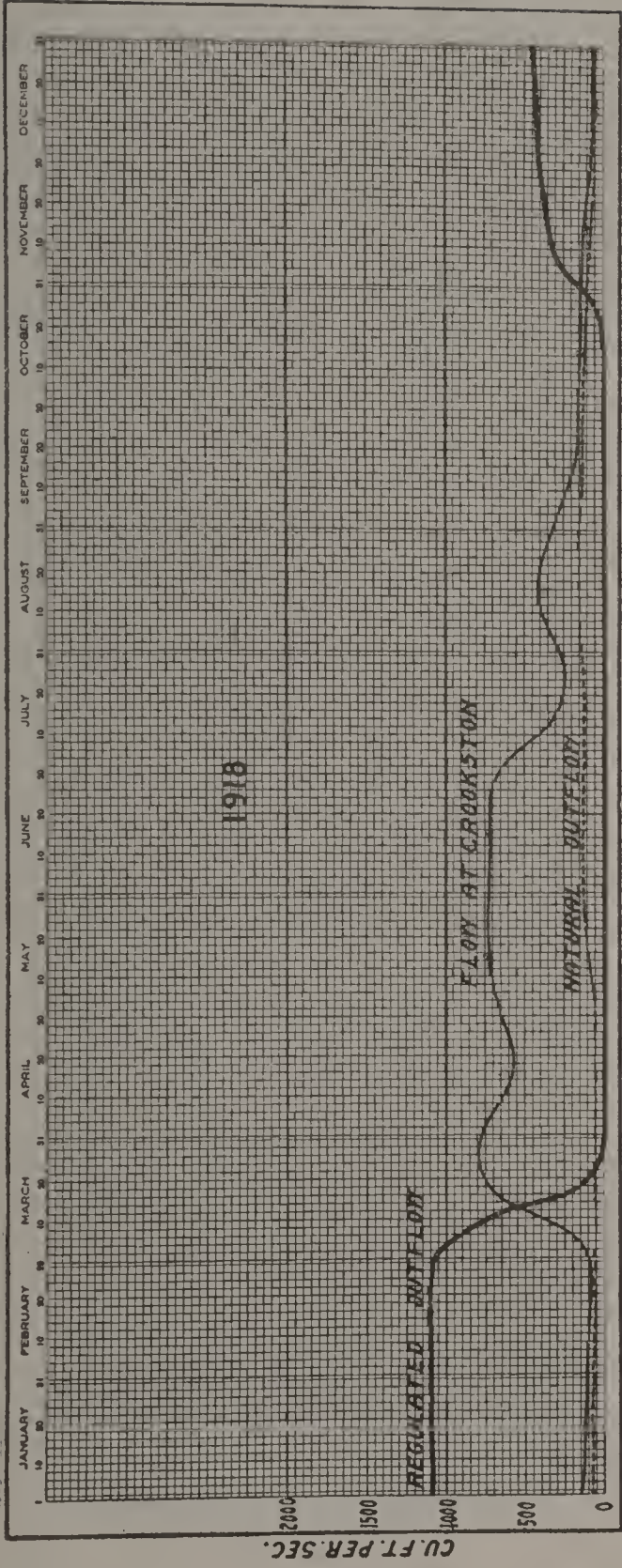
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

CHART NO. 16



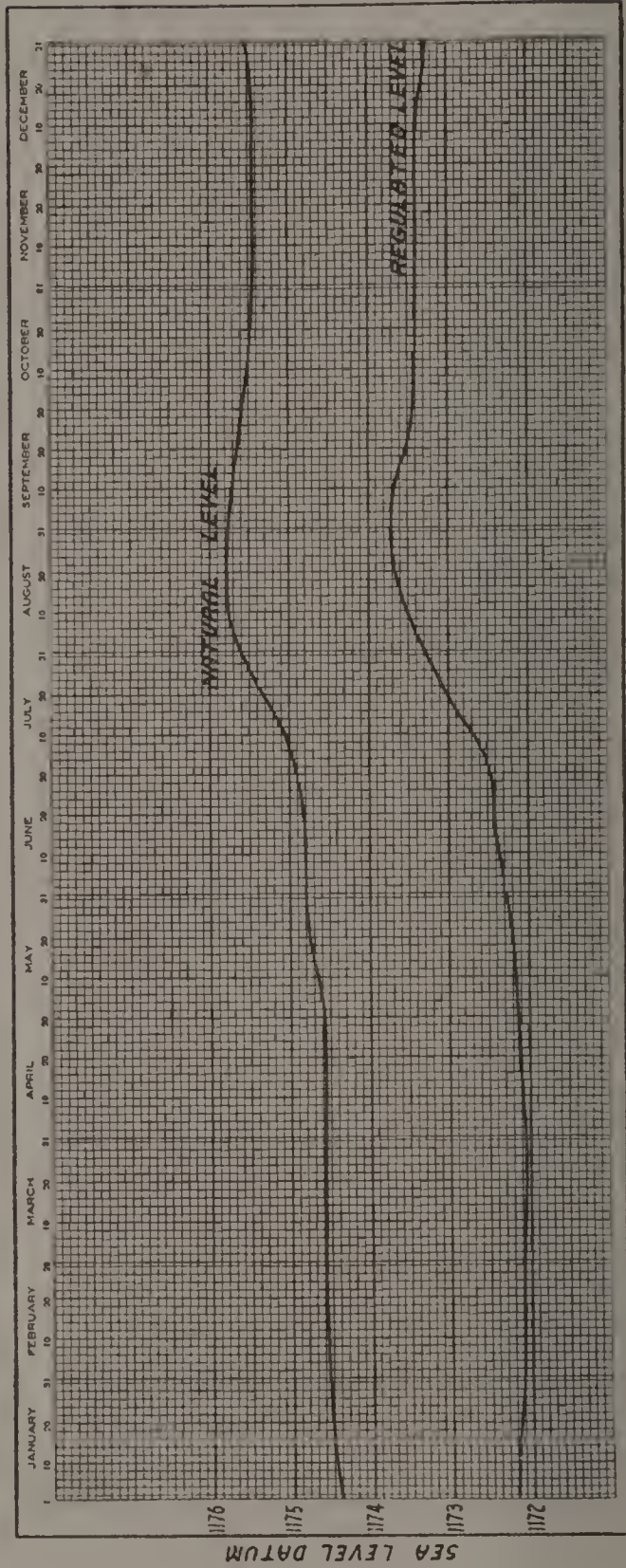
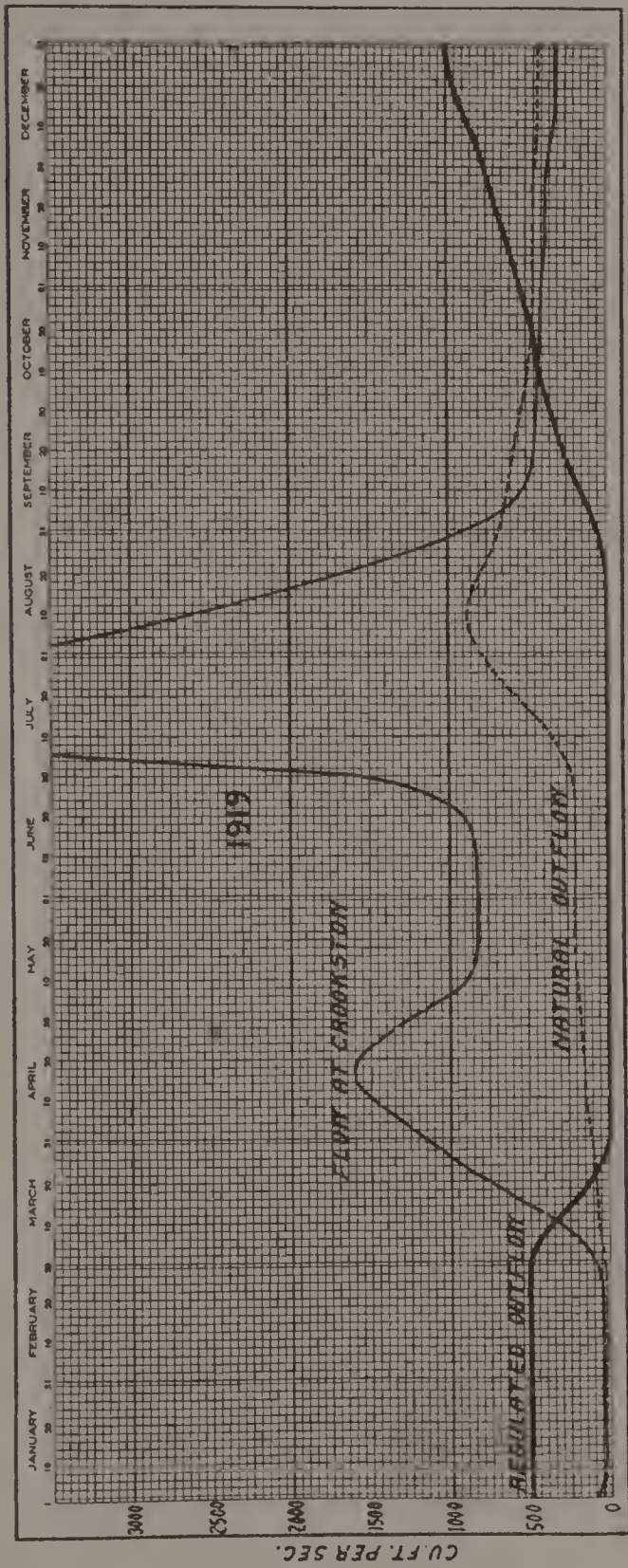
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

CHART NO. 17



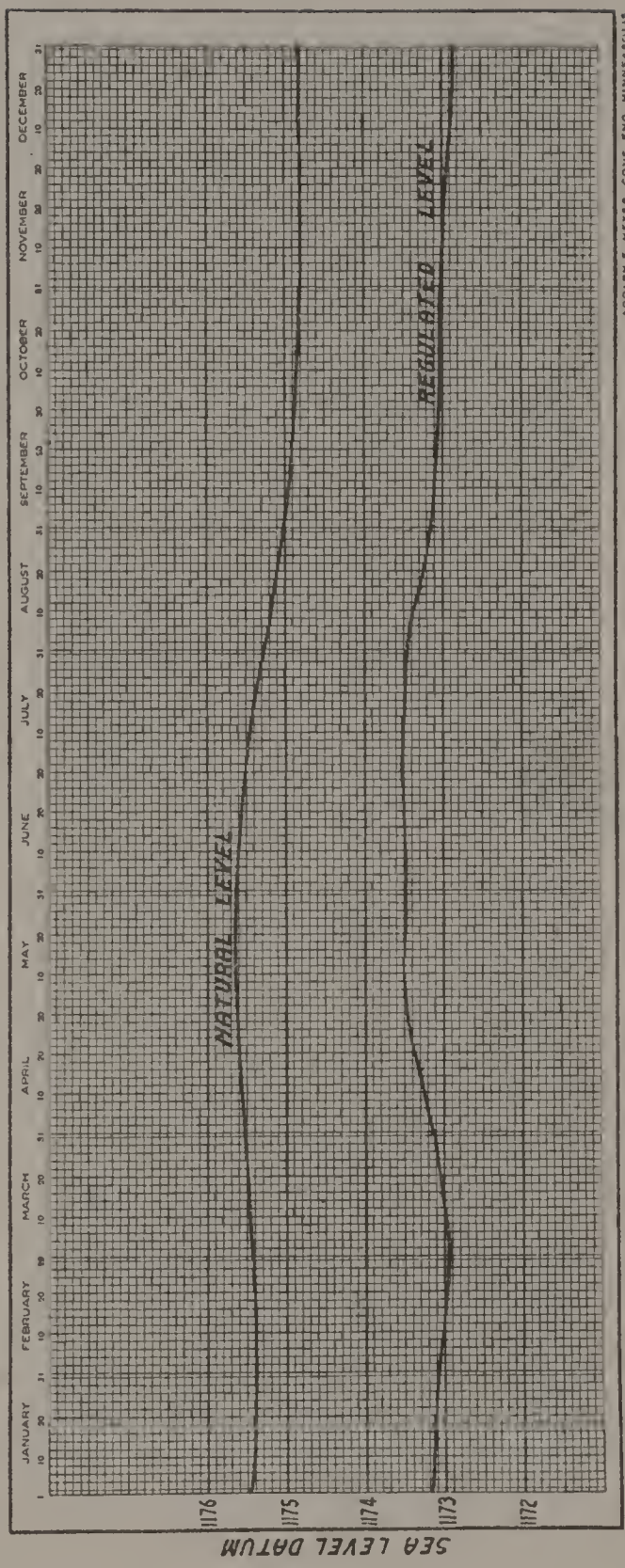
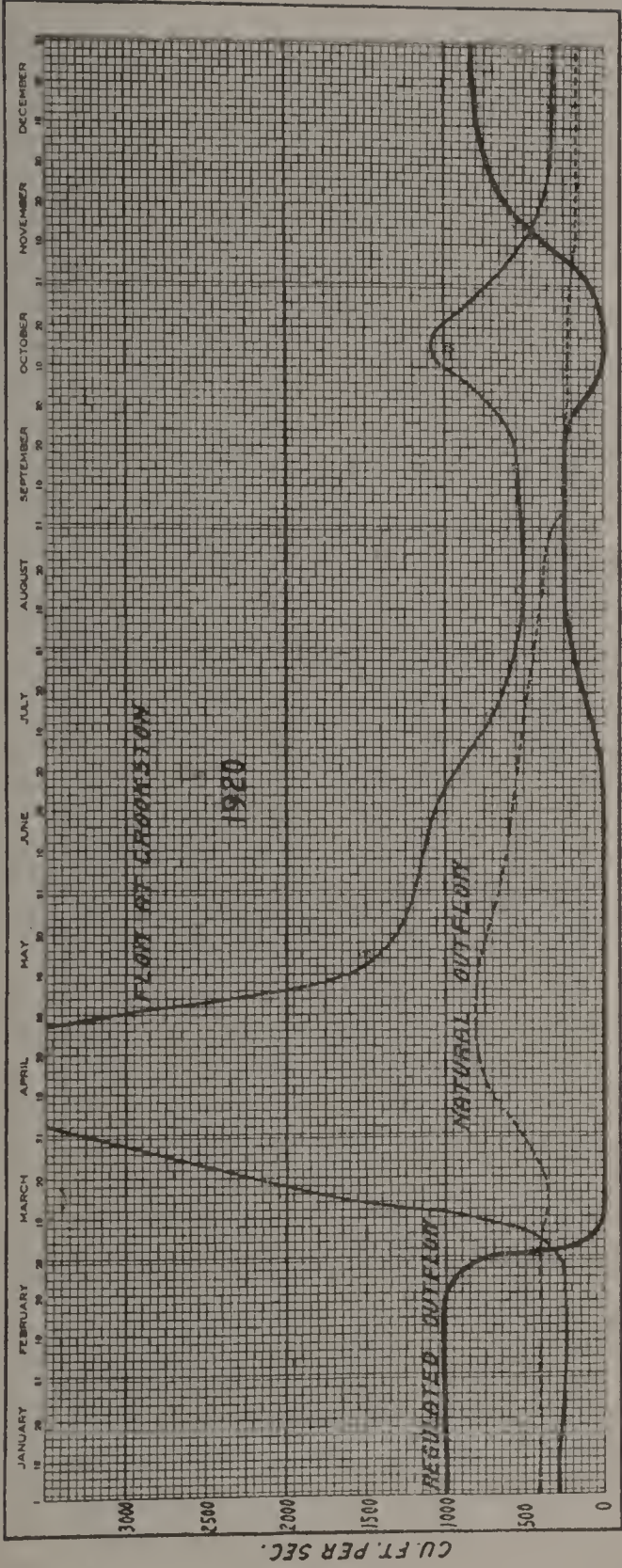
ADD. PH. F. MEYER, CONS. ENG. MINNEAP.

CHART NO. 18



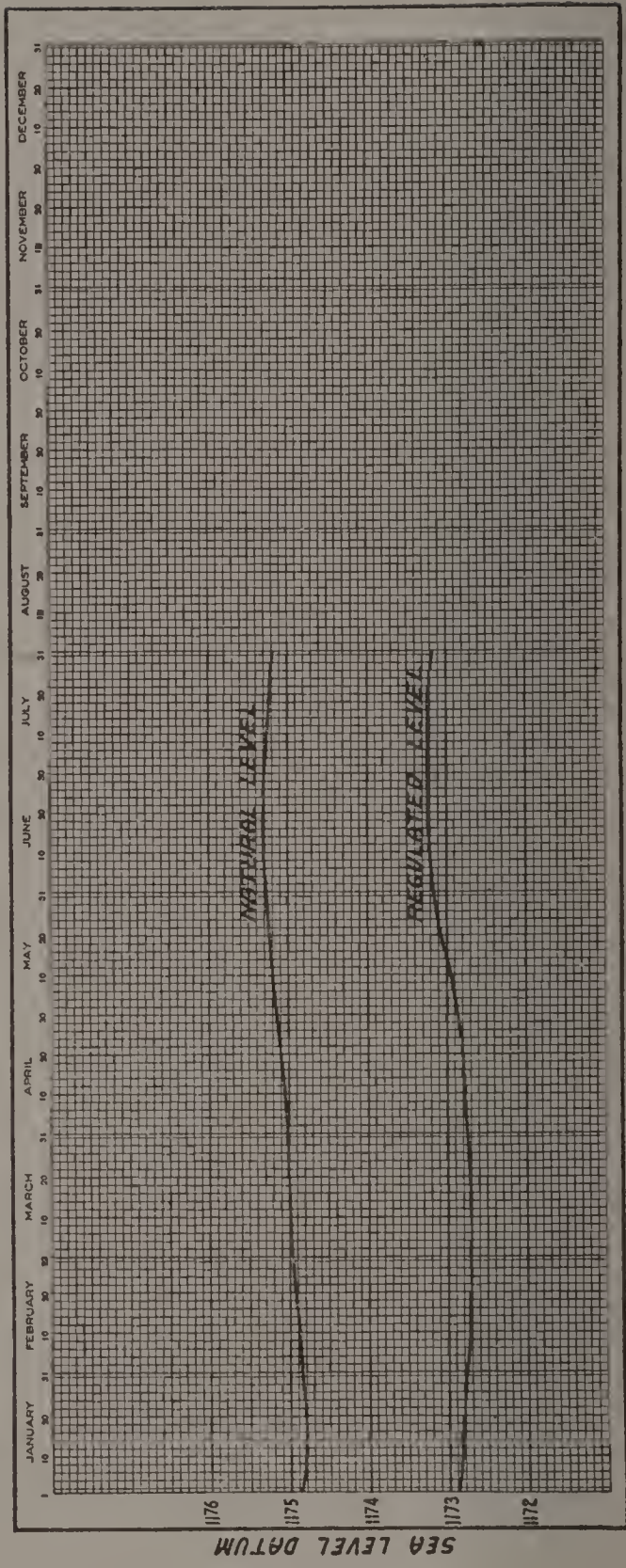
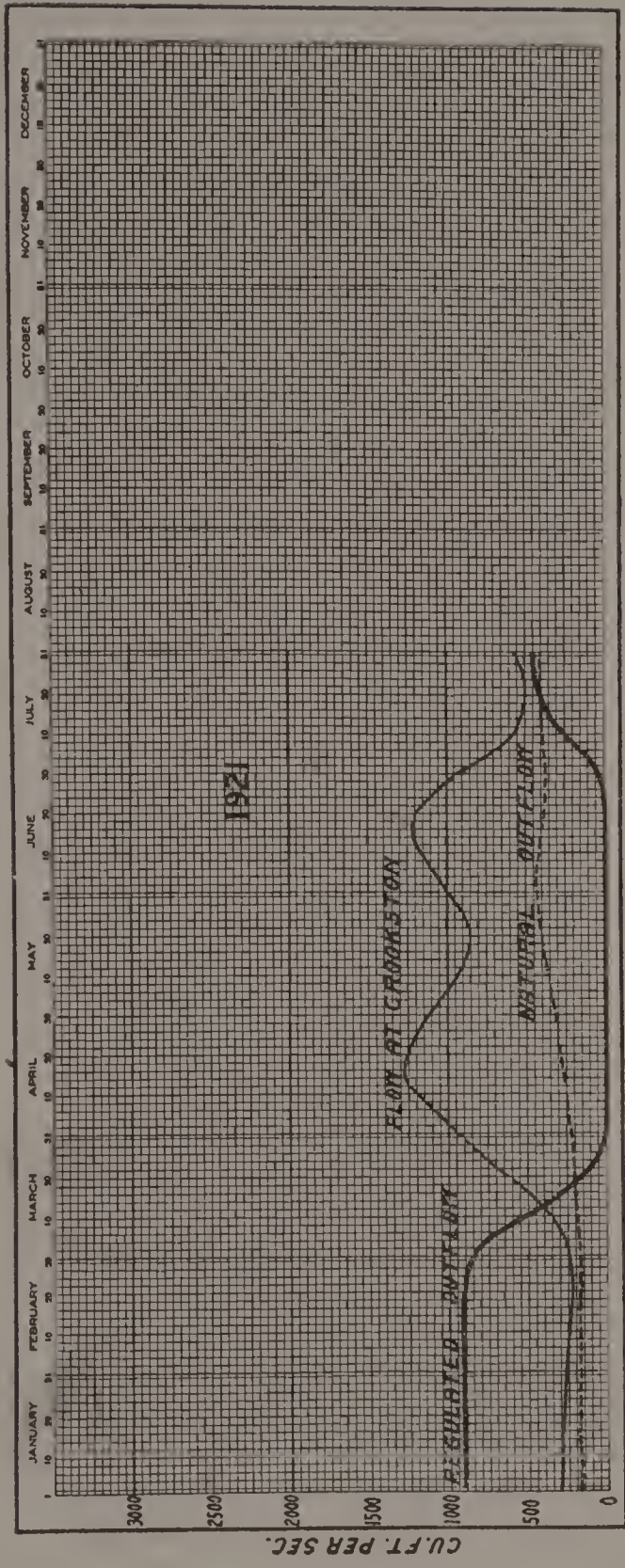
ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

CHART NO. 19



ADOLPH F. MEYER, CONS. ENG. MINNEAPOLIS

CHART NO. 20



ADOLPH F. MEYER, CONS. ENG., MINNEAPOLIS

CHART NO. 21







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